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THE MANCHESTER STEAM USERS' ASSOCIATION.

ESTABLISHED 1854.

MEMORANDUM BY CHIEF ENGINEER,

PRESENTED AT THE

ANNUAL MEETING

OF THE

GENERAL BODY OF THE MEMBERS,

HELD ON

TUESDAY, MAY 2nd, 1899.

MANCHESTER:
TAYLOR, GARNETT, EVANS, AND CO., LTD., BLACKFRIARS STREET.
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MANCHESTER STEAM USERS' ASSOCIATION.

ACCUMULATED FUNDS, £20,000.

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MEMORANDUM BY CHIEF ENGINEER.

MANCHESTER, *18th April, 1899.*

TO THE EXECUTIVE COMMITTEE.

GENTLEMEN,

I beg respectfully to report that during the past year the work of this Association has steadily and satisfactorily progressed. The offer which was made to our members to have the guarantees on their boilers increased by another £1,000 per boiler for the nominal sum of one shilling per annum, was readily taken advantage of. This change afforded an opportunity of amending the Guarantee form, and our members will by now be familiar with the new wording. Based on our past experience, the terms "Explosion," "Bulge," "Collapse," and "Wear and Tear" are now more clearly defined, so that misunderstandings, which sometimes occurred, need not be anticipated in future; besides, these terms are all in favour of the steam user, so that now, practically, every serious accident to a boiler while under steam is covered by our guarantee, unless it is caused by a wilful act, such as overloading the safety valve, &c.

In view of the repeated rulings of the Board of Trade Commissioners on boiler explosions, it has been thought necessary to point out to steam users generally that they are held morally liable for the safety of their boilers, steam pipes, &c. It should be mentioned that the fines which the Commissioners have the power to impose on any one who may have contributed towards an explosion can be enforced by imprisonment. *(See page 8, Eccles explosion.)* It is true that, so long as no explosion occurs, no Board of Trade inquiries are made, but in case of an explosion, the steam user is invariably blamed unless he has had the boiler examined by a competent man. In such cases he has to show that he had good grounds for believing that the boiler inspector was competent as such, and that the expert whose advice was sought as to the permissible working pressure, had the necessary technical knowledge for determining it. He has also to assure himself that the inspector thoroughly examined the boiler. If the inspector, whether he be competent or not, is in the employ of the steam user, the latter is, of course, responsible. In order, therefore, to relieve our members, not only of their pecuniary liability under the

various Acts, which is, of course, a matter of insurance, but also to relieve them of all moral responsibility as regards the safety of their boilers, the following words have been added to our guarantees :—

"This Guarantee is issued as a pledge of the integrity and efficiency of "the inspection of this boiler, and of the reliability of this report, and also "to protect steam users against the consequences of accidents to their boilers."

Those steam users who receive our guarantees are therefore sure that their boilers have been efficiently inspected, and as the inspectors are the servants of this Association, both the pecuniary and moral responsibility rests on our shoulders.

ACCIDENTS TO BOILERS.

The following case reported upon by the Board of Trade, No. 1130, was that of a boiler at Lymm, guaranteed by this Association.

The circumstances were these : During the exceptionally dry season of the past year, the ordinary water supply for this boiler gave out, and water from a disused well had to be used. This water was brackish and sedimentary, of which the owner was not aware. Salt and sediment rapidly accumulated in the boiler, and on the 26th July, 1898, the furnace bulged in two places over the firegrate. One of these bulges rent, and the steam and water were discharged through the opening. The attendant, who was engaged in front of the furnace, heard a strange noise inside, and just managed to step aside before the discharge of steam and water took place. The boiler was provided with a fusible plug, which did not act. The scale was generally thin, but over the two bulges it was fully half an inch thick. This accident was a highly instructive one, as it shows how, under certain conditions, a comparatively thin scale may lead to a collapse.

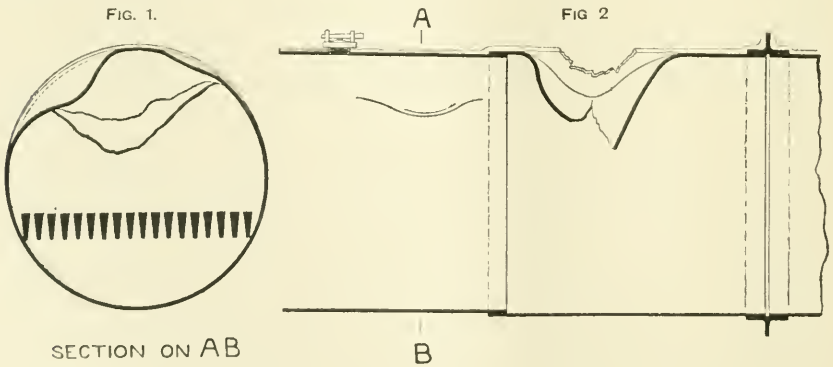


Fig. 1 shows a section through the furnace; the thick black line represents the iron furnace plate and the outlined part represents the boiler scale. This was still intact, as shown in the figure, when the boiler was

examined after the accident. It is quite clear that this scale, which was of a hard nature, did not adhere firmly to the furnace plate, and the two became detached, while the water and moist steam in the space between the two soon found their way through the porous scale, so that the enclosed space would then contain only superheated steam. This being as bad a conductor of heat as air, would allow the plate to grow red hot locally, and the bulge would become more and more pronounced as the iron grew softer.

The same process seems to have gone on as regards the other bulge; but possibly this one was started earlier or the plate was thinner; at any rate, the bulge grew so much that it burst, and thus caused the explosion. Although the pressure was about 40lbs. at the time, the scale over the fracture was not much broken. This is shown in Fig. 2. The water was found to be supersaturated with salt.

About the time of this accident two furnaces in a Lancashire boiler collapsed. Here, too, the ordinary feed supply had been stopped, and brackish and sedimentary water used; a soft scale was found in the boiler 2in. thick on the furnace crowns, and 9in. on the boiler bottom. The water was supersaturated with salt, and large salt crystals were found in the boiler after it was emptied. This was a modern steel boiler, with furnaces having flanged seams, and it is gratifying to find that no rent occurred although the bulges were about 5in. deep and the boiler was worked in this condition at 80lbs. pressure until sufficient steam could be raised in another boiler.

In another boiler a similar accident was only just prevented. The boiler had been in use for a few months, was cooled down, and emptied. On opening out, its inside was found coated with large crystals of salt. The water had, of course, been supersaturated, and probably another day's steaming would have resulted in a collapse. In this case, too, the feed had been changed.

In consequence of these cases following quickly one upon another, I addressed a letter at the time to the Engineering papers, pointing out that the drought might affect the purity of feed water, and that steam users should inquire into this matter before it was too late. After that no similar accidents occurred.

BOARD OF TRADE INQUIRIES.

During the past year I was called upon to give evidence before the Coroner, and subsequently also before the Board of Trade Commissioners, as to the cause of an explosion at Eccles (Board of Trade Report, No. 1,156, Slack Lane Dye Works, Eccles, 19th November, 1898). There could be no doubt that the boiler was too weak for the pressure, and also that it was very much wasted by corrosion. The visible defects

had been filled up with Portland cement, so that they could not be seen. The Commissioners were of opinion that the boiler-maker, who had examined the boiler and had bought it for the owner, was to blame, and he was fined accordingly, and has now been condemned to two months' imprisonment, unless the fine is paid within a month.

On the 6th January, 1899, the very disastrous explosion of a marine boiler took place at Barking. As there are few accidents to such boilers, I visited the scene to obtain, if possible, information on the working strength of such a boiler, and while thus employed was asked to give evidence before the local Coroner and also before the Board of Trade Commissioners. It appears that this boiler, which had formerly been in a steamer, had been used in the works up to about two years ago. It was then overhauled, repaired, tested by steam, and the safety valves set to blow at 70lbs. pressure. When it was decided to put the boiler into use again, it was closed up, filled with water, and steam was raised very gradually. The pressure gauge on the boiler was out of order and was replaced by another, which unfortunately was not a new one, and was apparently also out of order, so much so that at the time of the explosion, when there must have been nearly 240lbs. pressure in the boiler, the gauge only showed 16lbs. It is surprising that the man in charge, who had had ample experience in these matters, did not suspect the condition of affairs. The result was that the boiler exploded with terrific force, one part being hurled to a distance of 300 yards. The glass window panes of houses within a radius of 150 yards were mostly broken. A heavy wall of a shed, 30ft. wide, 30ft. high, and 18in. thick, and weighing many tons, was blown down. The chimney stack near the boiler was so much shattered that it fell and demolished part of the engineering shop; in fact, the whole of the works of Messrs. Hewett & Co., the owners, were demolished, and much damage done around them. The explosion was of technical interest. There is little doubt that the steam pressure which caused the explosion was close on 240lbs., and that the steam space stays gave way first and probably at their welds. Here the section of these stays was about $2\frac{3}{4}$ sq. in., while the area supported by each stay was about 196 sq. in., so that at 240lbs. pressure the stress on the material of the stays was about 17,100lbs. or 7·6 tons per square inch. This is a low yielding stress for welded iron, but can be explained by the experience that iron sometimes corrodes very irregularly, due probably to the numerous welded surfaces which traverse it. In this case the welds in the stays may have disintegrated, particularly as the boiler was old.

It was noticed that parts of the end plates in the steam space of the boiler were bulged. It is hardly likely that this bulging would have occurred before the explosion, otherwise there would have been an escape of steam, and the probability is that these plates were ready to yield when the explosion took place, and that an extra stress was thrown on them at that

instant. These plates were $\frac{11}{16}$in. thick. The pitch from stay centre to stay centre was 14in., the washers were 6in. diameter, and $\frac{1}{2}$in. thick. A customary safe working pressure for this construction would be about 90lbs. per square inch; but as these plates withstood a steam pressure of 240lbs., we may infer that the usual practice shows a factor of safety of at least $2\frac{5}{8}$. This value may be looked upon as small, but it must be remembered that the idea of factor of safety as evolved about fifty years ago, was that it should cover all errors and omissions which the engineers of those days might make when basing their calculations on the then ascertained strength of material. Even now we are rarely able to determine with any degree of precision what are the local stresses in structure, and the subject grows still more complicated when the structure is a boiler, and subjected to strains caused by internal heat. If, therefore, as is the case with boilers, a design is based on laboratory tests carried out cold, and a factor of safety of from four to six is adopted, then the experience gained by this explosion tells us that an allowance of about 50 per cent. has to be made when the same structure is heated.

The other flat plates in the boiler showed no distress. The combustion chamber plates were about $\frac{7}{16}$in. thick. The stays were pitched 8in. apart, and many were simply screwed into the plates, their ends riveted over, and these heads had disappeared. The customary permissible working pressure for this construction is about 70lbs. per square inch, so that here we have a factor of at least $3\frac{1}{2}$. Near the boiler bottom the plates were reduced to $\frac{1}{4}$in., so that for this part the factor would appear to have been even greater. The flat front plate between the two nests of tubes were $\frac{11}{16}$in. thick; the distance from centre to centre of edge rows of tubes was 15in. The customary working pressure for this construction would be 95lbs., so that for this part, which also showed no signs of having yielded, the factor was at least $2\frac{1}{2}$. The furnace was 34in. external diameter, and about $6\frac{1}{2}$ft. long at the top and $8\frac{1}{2}$ft. at the bottom. The bottom plate was about $\frac{1}{2}$in. thick, the top plate measured $\frac{7}{16}$in. generally, but along the line of firebars there were long wide spaces at which the metal was only $\frac{5}{16}$in. thick. The circumferential stress across these lines must have been 13,000lbs. or almost 6 tons per square inch. Hydraulic tests with furnaces of the above dimensions give an ultimate stress of between 7 and 9 tons per square inch before collapse takes place, and as the furnaces in this boiler did not give way, they might, under the condition of working this boiler, have resisted even a higher pressure. It must, however, be remembered that at the time of the explosion the fires were very low, and this case, therefore, throws no light on the question as to how high a stress may be allowed in furnace plates exposed to hot fires on one side and scale on the other. The experience of this Association is that when boilers are worked with forced draught the plates have to be made thick. Generally speaking, this explosion has shewn me that the customary scantlings of this Association for boilers are ample as regards safety.

PRACTICAL EXPERIENCE WITH REGARD TO THE STRENGTH OF BOILERS.

This explosion at Barking, and some experiences obtained with boilers submitted to us for inspection, led to an inquiry as to how far present practice as regards permissible working pressures in boilers is in harmony, or otherwise, with practical experience. This inquiry embraced certain experiences of this Association, Mr. Marten's reports on collapsed flues, the Board of Trade reports on collapsed flues, and experiences and experiments on other subjects. The whole investigation was laid before the Annual Meeting of the Institution of Naval Architects, and is here reproduced in a somewhat abridged and amended form, for the use of the members of this Association. The general conclusions based on this investigation are that many parts of boilers are often made stronger than is absolutely necessary, and wherever it is desired to design boilers of extreme lightness, the experiences detailed in the tables and diagrams will indicate what modifications might safely be made. It is gratifying to find that our past and present practice, as shown by this inquiry, is not only absolutely safe, but not unnecessarily severe, so that it has not been thought advisable to make any alterations. Several points have suggested themselves as regards which a saving in first cost might be effected, or subsequent wear and tear reduced; these will receive further attention.

Table IV. (p. 18) contains the results of hydraulic tests on experimental furnace tubes and also on actual furnaces in boilers. The leading dimensions are given, and also the ratios of half the diameters to the plate thicknesses, and also length of furnace to plate thickness. Besides these, the mean circumferential stress in the plate at the collapsing pressure is given. The ratios mentioned above were worked out for the purpose of ascertaining what relation, if any, existed between them and the collapsing stresses, which matter will be referred to shortly.

Table V. (p. 22) contains similar information about furnaces which have collapsed under steam pressure, presumably due to weakness. This information, as already stated, is compiled from Mr. Marten's tables, our own records of the same boiler explosions, and from the Board of Trade reports on explosions. This information cannot, of course, be looked upon as very reliable because of the destruction of the boilers. Only in rare cases is there any very definite information as to the actual steam pressure. Most furnaces are oval, and the collapsed ones may have been very oval; they may also have been covered with much scale or even grease, and possibly, too, the collapses may often have been due to shortness of water, or to pressures which were much higher than those stated.

Table VI. (p. 32) recapitulates all the cases in Table V. in which the furnaces were known to be oval.

Table VII. (p. 34) contains the details of oval furnaces which have not collapsed, although they were oval and although they were subjected to stresses which are frequently in excess of those estimated in Table V.

For convenience of comparison, all the more reliable cases are grouped in several diagrams numbered 1 to 14 (pp. 37—39); the general system adopted being to separate each set of cases into three groups according as to whether the stresses are high, medium, or low. Each group is contained on a separate diagram. If all the experiments of one table had been recorded on a single diagram they would have overlapped so much as to be confusing; now, however, it is possible to find the mean stress for each group, and the mean ratio of length to thickness, and to compare the two quantities. This has been done in the following table:—

TABLE I.

Diagram No.	Mean Stress. S	Mean $L \div t$ m	Product $S \times m$	$\sqrt{m}$	Product $S\sqrt{m}$	Remarks.
1	8·12	142	1152	11·9	96·8	Hydraulic Tests on Tubes.
2	12·63	61·2	773	7·82	98·8	
3	15·11	46·7	707	6·84	103·3	
				Mean	99·6	
7	1·43	752	1125	27·4	39·2	Steam Collapses of Flues.
8	2·10	299	629	17·3	36·3	
9	3·36	157	527	12·5	42·1	
				Mean	39·2	

This table also contains the products of the mean stresses into the ratio of length to thickness, and, according to Fairbairn's formula, one would expect this product to be nearly the same for each group. This is not the case. A more uniform result is obtained by taking the product of mean stress into the square root of the ratio of length to thickness *(see Table I.)*, which leads to the following two formulæ. The first one is for experimental flues tested to destruction by the hydraulic pressure $P_{II.}$ which produces a mean circumferential stress, $S_{II.}$

$$S_{II} = 98 \sqrt{\frac{t}{L}} \text{ tons} = 220{,}000 \sqrt{\frac{t}{L}} \text{ lbs.}$$

$$P_{II} = \frac{439{,}000 \cdot t}{D} \sqrt{\frac{t}{L}} \text{ lbs.}$$

The Co-efficients 98 and 220,000 have been obtained by taking the mean value of all the products of $S.\sqrt{L \div t}$. Here and in subsequent formulæ t is the thickness of the furnace plate, D the furnace diameter, and L its unsupported length, measured in inches.

The steam pressures P_s and the corresponding stresses S_s at which the furnaces mentioned in Table V. are said to have collapsed, are expressed as follows :—

$$S_s = 39{\cdot}2 \sqrt{\frac{t}{L}} \text{ tons} = 87{,}900 \sqrt{\frac{t}{L}} \text{ lbs.}$$

$$P_s = \frac{175{,}800 \cdot t}{D} \sqrt{\frac{t}{L}} \text{ lbs.}$$

It will be seen that in these formulæ, length has less influence than in Fairbairn's formula, and in this respect they are in agreement with a modified Fairbairn's rule by Mr. Longridge,

$$WP = \frac{177{,}300 \cdot t}{D} \cdot \frac{t}{\sqrt{L}} \text{ lbs.}$$

and with Mr. Fowler's modification.

$$WP = \frac{161{,}400 \cdot t}{D} \cdot \frac{t^{1{\cdot}19}}{\sqrt{L}} \text{ lbs.}$$

Here WP stands for safe working pressure.

On the other hand, both formulæ attach more importance to the thicknesses of the furnace plates than the experiences in Table V. and formulæ deduced from them seem to indicate.

On comparing the formulæ for S_H and S_s with the tables, the following discrepancies were noticed :—

TABLE II.

Running Number.	Stresses.		Excess by Formula.	Remarks.
	Actual.	By Formula.		
	Tons.	Tons.	Per cent.	
35	12·0	15·3	+ 22	Hydraulic Tests.
52	14·9	11·5	− 29	
37	12·8	9·9	− 30	
5	7·6	10·0	+ 24	
84	1·4	2·5	+ 44	Steam Pressure Collapses.
125	1·7	3·6	+ 53	
93	1·8	1·1	− 64	
135	4·5	2·7	− 67	

From the second half of this table it is clear that, as has already been suggested, and as is evident from the Diagrams 4 to 9, the information afforded by reports on collapses under steam pressure is not sufficiently complete to be relied upon.

In order to confirm this, and show that there have doubtless been other causes at work than the assumed steam pressures, all reported cases of collapsed oval furnaces have been collected in Table VI. and into Diagrams 11 and 12. As will be seen, Diagram 11 agrees fairly well with Diagram 5, which means that the average stresses at which oval furnaces collapsed are in excess of about 30 per cent. of the furnaces in Table V. (*see Diagram 4*), and are only exceeded by about 30 per cent. of the cases collected in Diagram 6. An examination of Table VII. and Diagrams 13 and 14 confirms this view. There we have thirty oval furnaces which have worked for years with stresses fairly high, as compared with the cases in Diagrams 4 and 5. There can also be no doubt that many long flues are working at stresses of from 1 ton to 1·5 tons per square inch; at least, many such cases are annually submitted to this Association for guarantee, and are reported upon as having been thus worked for years. Also in the case of the Barking explosion, as has already been mentioned, the stress in the furnace plate must have been about 6 tons per square inch under steam, and yet it did not fail. For these various reasons the matter has been looked at from the following point of view:—

Fox's corrugated flues have doubtless the stiffest section of any furnace in use, and although the pitch of the corrugations is 6in., this shape may be looked upon as equally as strong as a very short tube. These flues collapse cold at a stress of about 16 tons per square inch, so that we may assume that when the furnace is quite short, this is the maximum collapsing stress. On the other hand, Tables VI. and VII. and general experience indicate that if flues of even 30ft. length could be made with welded seams, truly cylindrical in shape and tested cold, with the same care as the various patent furnaces, such tubes would undoubtedly not collapse until a stress of three or more tons had been reached. These stresses of 16 and 3 tons are, therefore, looked upon as the approximate limits for short and for long furnaces. After several trials a formula has been evolved which not only adapts itself to these conditions, but also to the experimental results in Table IV. and Diagrams 1 to 3.

$$S_H = 3 + \frac{13}{1 + \left(\frac{L}{t}\right)^2 \frac{1}{13{,}000}} \text{ tons} = 3 + \frac{169{,}000}{13{,}000 + \left(\frac{L}{t}\right)^2} \text{ tons.}$$

Under S_H in Table IV. the stresses estimated by this formula have been placed. As will be seen, the agreement is reasonably close; the discrepancies are possibly due to difference in the crushing strength of the materials about which only very few experiments were made, or the shapes or thicknesses may have been irregular.

A somewhat similar formula might be constructed for Table V., but, as already explained, the information therein is too unreliable to be a guide;

but should it be desired to apply this formula to furnaces under steam pressure, the values should be reduced to at least one-third, or, better still, to one-fourth, unless experience should demonstrate that a larger stress is permissible. Thus, for instance, in the case of the Barking explosion, the formula would give one a collapsing stress of $5\frac{3}{4}$ tons if we adopt the local thickness of $\frac{5}{16}$in., or 4·2 tons if the more general thickness of $\frac{7}{16}$in. is adopted. The case is similar to the Tube No. 12, Table IV., which collapsed at 4·4 tons, and it shows that under the conditions of working the boiler at the time of the explosion the furnace was not being subjected to exceptional strains.

OVAL FURNACES.

When furnaces have lap joints instead of having welded or butt strapped ones, they must be looked upon as being somewhat oval, and the natural tendency of oval furnaces is to get still further out of shape as the pressure increases. The amount could be calculated if the sections were truly elliptical, but irregularity of shape, the stiffness of riveted seams, &c., introduce errors, which can only be corrected with the help of actual experiments such as were carried out by Mr. Longridge (see Table IV., Nos. 23 to 26). If we write S for the maximum local stress, and S_1 for the mean circumferential stress, and 4Δ for the difference between the largest and smallest cross diameters at any section, then the experiments show that

$$S = S_1 \left(1 + \frac{6 \cdot \Delta \cdot t}{t^2 - \frac{S_1 D^2}{65{,}200{,}000}} \right) \text{lbs.}$$

For iron the limit for S is reached at or about 27,000lbs. If we reduce this stress by a suitable factor so as to fix on a safe working pressure, and then compare the experimental collapsing stress with this working pressure, the factor so found is not the same as the above; but this is the customary factor of safety, whereas the actual one is greater. It will thus be seen that the factor of safety does not always give a true idea of the safety of a structure. In the case of oval furnaces the true factor is in excess of the apparent one, *i.e.*, furnaces are safer than incomplete theories would make them appear.

GROOVING.

An inquiry into the longitudinal expansion of furnaces revealed that when the end plates are very thick, as they have to be for high pressures, very severe local stresses must be set up at the furnace flanges and gusset rivets whenever the furnace tops get coated with scale or grease, more particularly when fires are intense. This, doubtless, explains the cause of frequent grooving in the furnace flanges. At any rate, grooving does not

occur where grease and mineral matter are kept out of a properly-constructed Lancashire or Cornish boiler. It was also found that if these boilers are fitted with corrugated furnaces their flanges do not groove, although cracks may appear at the level of the firebars if scale is allowed to accumulate. It has, therefore, been decided to fit short corrugated tubes at the back ends of the internal flues of Lancashire boilers intended to be worked hard and at high pressures. It is hoped that with this arrangement grooving will be prevented, or at least mitigated. It is also hoped that when more experience has been gained with this construction, the general design of boilers may be improved upon.

RIVETED JOINTS.

The question of strength of riveted joints has also been inquired into. It has long been known that wide test pieces show a relatively higher tenacity if they have holes drilled into them than if they are uniform in section over their length, so that a riveted joint with its numerous rivet holes ought to be stronger than the results of tearing test pieces would show. On the other hand, it is evident that stresses in the plates are more severe close to the rivets than between them, and also that the wider the rivets are placed apart the severer will be the local stresses. A comparison with experiments on riveted joints showed that the nominal percentage of the steel plate between the rivets has to be multiplied by a factor $1{\cdot}2\sqrt[4]{\frac{d}{l-d}}$, so that the actual percentage of a double butt strapped joint is $B_1=\frac{120\,(l-d)^{\frac{3}{4}}\,d^{\frac{1}{4}}}{l}$ where l is the pitch of rivets and d their diameter.

This formula agrees fairly well with Dr. A. B. W. Kennedy's experiments on riveted joints; but it is of importance chiefly as an indication that although we can design riveted joints with nominal percentages even above 90 per cent., the actual relative strength is never more than about 68 per cent. of the solid plate, and this maximum occurs with a double butt strapped joint of nominally 75 per cent. Seams of higher percentages are therefore not only more costly, but actually a little weaker than those of nominally 75 per cent. strength. The real factor of safety of a high percentage joint is therefore not so great as the nominal one, whereas the low percentage joints are stronger than their nominal value. *(See Table III.)*

TABLE III.

Pitch : diameter	2	3	4	5	6	7	8
Nominal Percentage = B ...	50	66·7	75	80	83·4	85·7	87·5
Actual Percentage = B_1	60	67·3	68·4	67·9	66·9	65·7	64·6

Generally these inquiries show that the practice adopted by this Association as regards the fixing of working pressures is safe. As regards designs for new boilers, the scantlings are somewhat heavier than are required for safety, but our members rarely suggest a departure towards thinner plates, for, besides safety, they also expect immunity from boiler troubles, whereas extra weight, except in so far as it affects the cost, is of minor importance. Where lightness is essential, as, for instance, on account of transport, it will generally be more advantageous to decide on a light type of boiler, such as the water-tube, than to lighten the existing types.

EXPLANATION OF TABLES AND DIAGRAMS.

Table IV. contains the results of 53 hydraulic tests on experimental tubes and on furnaces. Columns 9 and 10 give the ratios of radii and of lengths to thicknesses whose logarithms have been used as ordinates in the diagrams. The stresses in column 12 are also noted against each experiment in the diagram. The experiments of this table have been distributed over four diagrams. The experiments on lap-jointed and oval furnaces will be found in Diagram 10. Those experiments on welded and butt-strapped tubes in which the tubes failed at a low, medium, or high stress will be found respectively in Diagrams 1, 2, or 3.

Table V. contains details of actual furnaces which collapsed under steam, and which are believed to have been too weak for the pressures. Collapses which are distinctly due to shortness of water, scale, or grease are not included in this table. All oval furnaces are repeated in Table VI. Furnaces which may have given way due to other causes than weakness of the flue are included in the table, but are not transferred to the diagrams. These cases include badly stayed end plates, bad repairs, excessive local corrosion whereby the plate has been reduced to less than one-third of its original thickness.

This Table V. contains 119 cases, viz., from No. 54 to 172. Of these 16 were unquestionably oval furnaces, 22 were doubtful cases, and 3 were hydraulic tests, leaving 78 cases which have been distributed in Diagrams 4 to 9. The arrangement of the columns is similar to that of Table IV., except that the original and the reduced thickness are given, and also the mean stresses on the original and on the reduced sections. In Diagrams 4, 5, and 6 the former are grouped, the one containing low stress, the other medium, and the third the highest stresses. The same arrangement is adopted in Diagrams 7, 8, and 9, which give the stresses on the reduced sections. In these three last diagrams the ordinates are those found by dividing the radius or the length by the original thickness, which, on the whole, seems the fairest plan. Should it be desired to use ordinates found by dividing the dimensions by the reduced thickness, this

can easily be done by shifting the points at an angle of 45° upwards, and to the right. The distance is fixed by the ratio of original to reduced thickness. The scale can easily be marked off from the diagram.

Table VI., as already mentioned, is an extract from Table V., and contains the 16 oval or deformed furnaces. The stresses are plotted down in Diagrams 11 and 12 on the same principle as that adopted above.

Table VII. contains thirty cases (Nos. 173 to 202) of furnaces which had worked for years in an oval condition. The mean stresses, both for the original and for the reduced thickness, have been worked out, and the results plotted in Diagrams 13 and 14 on the same plan as that adopted in previous cases.

Diagrams.

The diagrams 1 to 14 (pp. 37—39) are divided, both horizontally and vertically, by lines spaced at logarithmic intervals, of which the numbers are the ratios—Length of furnace divided by thickness of plate, and diameter of furnace divided by twice the thickness of plate. These ratios are worked out in the tables for each individual tube or furnace, and its position is thereby fixed in the diagrams. The numerals against the points thus found are the mean circumferential stresses found by multiplying the ratio of the diameter to twice the thickness into the pressure to which the furnace was subjected.

TABLE IV.

Hydraulic Tests of Experimental Furnace Tubes and Boilers.

Running Number.	Diagram.	Authority.	Cylindrical Experimental Tube.							Collapsing Pressure.	Mean Stress in Plate.	S_H by Formula.	Remarks.
			Material.	Longitudinal Seam.	Thickness. t.	Diameter. D.	Unsupported Length. L.	Ratio. $\frac{D}{2t}$	Ratio. $\frac{L}{t}$				
					In.	In.	In.			Lbs.	Tons.	Tons.	
1	10	Shock.	Iron.	Butt.	·25	71	54	142	216	128	8·1	—	$\frac{1}{2}$in. oval.
2	10	,,	,,	,,	·23	71	54	154	235	105	6·7	—	$\frac{1}{2}$in. oval.
3	1	,,	,,	,,	·25	71	27	142	108	134	9·2	9·7	Adamson's Ring.
4	1	Board of Trade.	,,	,,	·25	54	24	108	96	128	8·4	10·6	Adamson's Ring.
5	1	Knight.	,,	Weld.	·25	36	24	72	96	235	7·6	10·6	
6	1	,,	,,	,,	·25	36	48	72	192	217	7·0	5·7	
7	10	Fairbairn.	,,	Lap.	·25	$18\frac{3}{4}$	61	37	244	420	7·0	—	
8	10	M.S.U.A.	,,	,,	·28	$34\frac{3}{4}$	43	62	154	160	4·7	—	Vertical boiler; 2 cross tubes; uptake.
9	10	Fairbairn.	,,	,,	·34	$33\frac{1}{2}$	360	50	1,059	99	2·2	—	
10	10	Board of Trade.	,,	,,	·344	$44\frac{3}{8}$	$38\frac{1}{2}$	64	112	200	5·8	—	Vertical boiler.
11	10	,,	,,	,,	·375	43	46	57	123	180	4·6	—	Vertical boiler.
12	1	,,	,,	Weld.	·375	38	84	51	224	$187\frac{1}{2}$	4·4	5·7	

TABLE IV.—(*continued.*)

Running Number.	Diagram.	Authority.	Cylindrical Experimental Tube.							Collapsing Pressure.	Mean Stress in Plate.	S_M by Formula.	Remarks.
			Material.	Longitudinal Seam.	Thickness.	Diameter.	Unsupported Length.	Ratio.					
					t.	D.	L.	$\frac{D}{2t}$	$\frac{L}{t}$				
					In.	In.	In.			Lbs.	Tons.	Tons.	
13	10	M.S.U.A.	Iron.	Weld.	·375	33	35¼	44	94	310	6·1	—	Adamson's Rings; did not collapse at 310.
14	10	Fairbairn.	,,	Lap.	·375	42	420	56	1,120	97	2·4	—	
15	10	,,	,,	,,	·375	42	300	56	800	127	3·2	—	
16	1	Knight.	,,	Weld.	·375	36	24	48	64	468	10·0	12·9	
17	1	,,	,,	,,	·375	36	48	48	128	390	8·4	8·8	Adamson's Ring.
18	10	M.S.U.A.	,,	Lap.	·38	38½	45	51	122	240	5·4	—	Vertical boiler; 2 cross tubes; uptake and stays.
19	1	Board of Trade.	Steel.	Weld.	·42	32	94	38	224	370	6·3	5·7	
20	1	,,	,,	,,	·42	32	46	38	109	600	10·2	8·2	Adamson's Ring.
21	1	,,	Iron.	,,	·5	38	86	38	172	450	7·6	7·0	Adamson's Ring.
22	10	,,	,,	Lap.	·531	37	108	35	204	260	4·0	—	Old boiler.
23	10	Longridge, 1898.	,,	,,	·365	33·3	222	46	609	110	2·2	—	Old boiler. Flue oval ⅜in.
24	10	,,	,,	,,	·365	33·3	222	46	609	60	1·2	—	Old boiler. Flue oval 1·31in.
25	10	,,	,,	,,	·354	33·3	222	47	628	100	2·1	—	Old boiler. Flue oval 1·45in. This measurement is said to be doubtful.

TABLE IV.—*(continued.)*

Running Number.	Diagram.	Authority.	Cylindrical Experimental Tube.							Collapsing Pressure.	Mean Stress in Plate.	S_H by Formula.	Remarks.
			Material.	Longitudinal Seam.	Thickness. t.	Diameter. D.	Unsupported Length. L.	Ratio. $\frac{D}{2t}$	Ratio. $\frac{L}{t}$				
					In.	In.	In.			Lbs.	Tons.	Tons.	
26	10	Longridge, 1898.	Iron.	Lap.	·354	33·3	222	47	628	85	1·8	—	Old boiler. Flue oval $\frac{5}{8}$in.
27	3	(Morrison's Paper.) (N.E.C.I.E.S., 1883)	Steel.	Weld.	·47	43	19	46	40	700	14·6	14·6	Oval 0·15in.
28	3	,,	,,	,,	·55	43	23	39	42	840	14·8	14·4	
29	2	,,	,,	,,	·55	43	23	39	42	760	13·8	14·4	
30	3	,,	,,	,,	·55	43	23	39	42	840	14·8	14·4	
31	3	,,	,,	,,	·55	43	23	39	42	835	14·6	14·4	
32	3	,,	,,	,,	·55	43	23	39	42	814	14·3	14·4	
33	2	Germ. Adm. No. 11	,,	,,	·50	38	30	38	60	712	11·6	13·2	
34	2	,, ,, 11	,,	,,	·50	38	28	38	54	682	11·4	13·6	
35	2	,, ,, 11	,,	,,	·50	38	21	38	41	726	12·0	14·5	Did not collapse.
36	1	,, ,, 1	Iron.	Butt.	·33	40	42	61	129	342	9·4	8·7	
37	2	,, ,, 2	,,	,,	·29	40	29	67	98	427	12·8	10·5	
38	2	,, ,, 3	,,	,,	·3	40	20	62	63	427	11·9	12·9	
39	2	,, ,, 4	,,	,,	·31	40	13	65	42	427	12·3	14·4	Measured flange to angle hoop.

TABLE IV.—*(continued.)*

Running Number.	Diagram.	Authority.	Cylindrical Experimental Tube.							Collapsing Pressure.	Mean Stress in Plate.	S_L by Formula.	Remarks.
			Material.	Longitudinal Seam.	Thickness. t.	Diameter. D.	Unsupported Length. L.	Ratio. $\frac{D}{2t}$	Ratio. $\frac{L}{t}$				
					In.	In.	In.			Lbs.	Tons.	Tons.	
40	2	Germ. Adm. No. 4	Iron.	Butt.	·31	40	26	65	85	427	12·3	11·4	Measured flange to flange. Hoop studs tore.
41	1	,, ,, 5	,,	,,	·45	40	73	44	162	455	9·0	7·3	
42	2	,, ,, 6	,,	,,	·44	40	42	45	96	641	12·9	10·6	
43	2	,, ,, 7	,,	,,	·43	40	19	46	45	641	13·2	14·2	Measured flange to angle hoop.
44	2	,, ,, 8	,,	,,	·43	40	28	47	66	641	13·3	12·7	
45	3	,, ,, 9	,,	,,	·44	40	13	44	31	783	15·5	15·1	Measured flange to angle hoop.
46	3	,, ,, 9	,,	,,	·44	40	25	44	58	783	15·5	13·3	Measured flange to flange. Hoop studs tore.
47	2	,, ,, 10	,,	,,	·49	38	20	39	41	783	13·5	14·1	
48	2	,, ,, 10	,,	,,	·52	38	30	37	62	812	13·2	13·0	Did not collapse.
49	3	,, ,, 12	,,	,,	·60	38	21	31	36	1138	15·8	14·8	Did not collapse.
50	3	,, ,, 12	,,	,,	·60	38	30	31	50	1138	15·8	13·9	Did not collapse.
51	3	,, ,, 12	,,	,,	·60	38	27	31	45	1138	15·8	14·2	Furnace neck is of reduced diameter.
52	3	,, ,, 13	,,	,,	·59	40	43	34	72	997	14·9	12·3	
53	3	,, ,, 13	,,	,,	·59	40	36	34	61	997	14·9	13·1	Did not collapse.

TABLE V.

DETAILS OF COLLAPSED CYLINDRICAL FURNACES OF CORNISH (C), LANCASHIRE (L), AND VERTICAL (V) BOILERS. COLLECTED FROM MR. E. MARTEN'S REPORTS AND MANCHESTER STEAM USERS' ASSOCIATION'S RECORDS, BOTH PRIOR TO 1879, AND BOARD OF TRADE REPORTS FROM 1882. ALL FURNACES IN THIS LIST ARE IRON LAP-JOINTED, EXCEPT WHERE NOTED.

Running Number.	Diagram.	Authority, Date, or Official Number.			Boiler Type.	Furnace Age.	Details of Furnace.						Probable Collapsing Pressure.	Mean Stresses on		Reported Scale on Furnace.*	* Remarks against Mr. Marten's cases are chiefly from M.S.U.A. Records. Unless otherwise recorded, vertical boilers have a vertical uptake, but no crown stays, and the crown is dished.
							Thickness.		Diameter.	Length.	Ratio.			Original Section.	Reduced Section.		
							Original. t	Reduced.	D	L	$\frac{D}{2t}$	$\frac{D}{L}$					
						Years.	In.	In.	In.	In.			Lbs.	Tons.	Tons.		
54	5, 7	Marten	1866	4	C	16	$\frac{3}{8}$	$\frac{3}{8}$*	42	336	56	896	45	1·1	1·1	None	Furnaces used to pant until stayed by rods.
55	—	,,	,,	12	C	Old	$\frac{3}{8}$	$\frac{3}{8}$*	35	252	47	673	64	1·3	1·3	—	No gussets to end plates.
56	5	,,	,,	13	C	6‡	$\frac{3}{8}$	—	44	381	59	1,016	40	1·0	—	—	Furnace had been patched.
57	11	,,	,,	20	C	—	$\frac{7}{16}$	—	48	360	55	825	43	1·0	—	—	Oval; no information, M.S.U.A.; pressure probably exceeded.
58	—	,,	,,	29	C	—	$\frac{7}{16}$	—	48	368	55	843	40	1·0	—	—	Possibly shortness of water.
59	6	,,	,,	62	C	—	$\frac{7}{16}$	—	37	195	42	451	87	1·6	—	—	Three bricks on lever; WP = 62lbs.
60	5	,,	1867	19	C	20	$\frac{3}{8}$	—	46	384	61	1,023	40	1·1	—	—	Spare boiler; exploded while raising steam.
61	—	,,	,,	23	C	1*	$\frac{5}{16}$*	$\frac{5}{16}$*	36	246	57	787	64	1·6	1·6	Thin	Ends blew out; flue plates $\frac{3}{8}$ and $\frac{5}{16}$in.

* These cases, or details, in various columns, have been corrected from the detailed reports in the Records of the Manchester Steam Users' Association. Compare with Mr. E. Marten's reports and Mr. J. Samson's report on the Brierley Hill Explosion, 1882, Parl. Paper, C.—3,277.

† One end of furnace was either spherical or conical, and therefore had no ring support.

‡ These boilers are older than stated, having been bought second-hand, &c.

TABLE V.—(*continued.*)

Running Number.	Diagram.	Authority, Date, or Official Number.	Boiler Type.	Furnace Age.	Details of Furnace.						Probable Collapsing Pressure.	Mean Stresses on		Reported Scale on Furnace.*	* Remarks against Mr. Marten's cases are chiefly from M.S.U.A. Records. Unless otherwise recorded, vertical boilers have a vertical uptake, but no crown stays, and the crown is dished. ‡
					Thickness.		Diameter.	Length.	Ratio.			Original Section.	Reduced Section.		
					Original. t	Reduced.	D	L	$\frac{D}{2t}$	$\frac{D}{L}$					
				Years.	.	In.	In.	In.			Lbs.	Tons.	Tons.		
62	5, 7	Marten 1867 35	C	5*	$\frac{3}{8}$	$\frac{3}{8}$*	35	312	47	832	60*	1·2	1·2	—	
63*	—	,, 1868 3	C	—	$\frac{3}{8}$	$\frac{3}{8}$*	45	316	60	843	15	0·4	0·4	—	No gussets; not short of water.
64	6	,, ,, 12	C	—	$\frac{1}{4}$	—	32	180	64	721	60	1·7	—	—	No information, M.S.U.A.
65	5	,, ,, 14	C	—	$\frac{5}{16}$	—	48	408	64	1,088	40	1·1	—	—	No information, M.S.U.A.
66	6	,, ,, 22	L	12*	$\frac{3}{8}J$*	—	36	324	48	864	76*	1·6	—	Thin	Valve in order; old seam rip in furnace.
67*	—	,, ,, 39	C	—	$\frac{1}{2}$	—	45	282	45	564	40	0·8	—	—	Shortness of water.
68*	11	,, ,, 42	C	4*	$\frac{5}{16}$*	—	33	180	53	575†	50	1·2	—	—	4in. oval at front end; intermediate cone back end (24in.diam.)collapsed.
69	6	,, 1869 7	C	—	$\frac{7}{16}$	$\frac{7}{16}b$*	52	450	59	1,028	75*	2·1	—	None	Back end collapsed.
70	4—	,, ,, 30	C	13*	$\frac{3}{8}$	$\frac{3}{8}$*	34	384	45	1,023	45	0·9	0·9	$\frac{3}{16}$	Bad iron.
71	5, 7	,, ,, 35	C	—	$\frac{7}{16}$	$\frac{3}{8}$*	48	384	55	879	50	1·2	1·4	—	Not short of water.
72	6	,, ,, 54	C	—	$\frac{3}{8}$*	—	48	384	64	1,023	36*	1·4	—	—	
73	5	,, ,, 56	C	—	$\frac{3}{8}$	—	46	312	61	832	40	1·1	—	—	No details, M.S.U.A.

* See note, page 22. † See note, page 22. ‡ See note, page 22.

TABLE V.—(*continued.*)

Running Number.	Diagram.	Authority, Date, or Official Number.	Boiler Type.	Furnace Age.	Details of Furnace.						Probable Collapsing Pressure.	Mean Stresses on		Reported Scale on Furnace.*	* Remarks against Mr. Marten's cases are chiefly from M.S.U.A. Records. Unless otherwise recorded, vertical boilers have a vertical uptake, but no crown stays, and the crown is dished.
					Thickness.		Diameter.	Length.	Ratio.			Original Section.	Reduced Section.		
					Original. t	Reduced.	D	L	$\frac{D}{2t}$	$\frac{D}{L}$					
				Years.	In.	In.	In.	In.			Lbs.	Tons.	Tons.		
74	4—	Marten 1870 1	C	13*	$\frac{3}{8}$	$\frac{3}{8}$*	39	360	52	960	30	0·7	0·7	$\frac{1}{32}$	Gussets very weak.
75*	4—	,, ,, 16	C	Very old	$\frac{3}{8}$	$\frac{3}{8}$*	46	408	61	1,087	33*	0·8	0·8	—	Signs of higher pressure; 45lbs. if weights on lever end.
76	6	,, ,, 21	C	3*	$\frac{3}{8}$	—	36	312	48	832	86*	1·8	—	—	Possibly higher pressure.
77*	11, 12	,, ,, 25	C	2†*	$\frac{1}{4}$*	$\frac{1}{4}$*	36	252	72	1,008	40	1·3	1·3	$\frac{1}{8}$	Oval and cracked; sometimes extra load on lever.
78*	5, 7	,, ,, 26	C	12*	$\frac{3}{8}$	$\frac{3}{8}$*	36	343	48	915	50	1·1	1·1	—	Longitudinal seams in line; pitting.
79*	6	,, ,, 48	C	10*	$\frac{3}{8}$	—	42	159	56	424	60	1·5	—	Thick greasy	Safety-valves jammed; bad workmanship; furnace plates 80in. long.
80	5, 7	,, ,, 54	C	12	$\frac{3}{8}$	$\frac{1}{4}$*	45	432	60	1,152	38	1·0	1·5	—	A furnace had collapsed five years previously.
81*	4	,, 1871 32	C	1†*	$\frac{3}{8}$	—	36	336	48	900	40	0·9	—	—	Not short of water.
82	5	,, ,, 33	C	7*	$\frac{3}{8}$	—	36	516	48	1,376	50	1·1	—	Thin	Rent $\frac{3}{16}$in. local; three weeks previously, new furnace bottom.
83	5	,, ,, 46	C	18	$\frac{5}{16}$	—	48	393	61	1,255	45	1·2	—	—	Not short of water.
84*	6, 7	,, 1872 15	V	—	$\frac{3}{8}$	$\frac{3}{8}$*	51	90	68	240	45	1·4	1·4		Plated vertically; $4\frac{1}{2}$in. waterspaces.
85*	4	,, ,, 20	C	10	$\frac{7}{16}$	—	30	216	34	494	55	0·8	—	—	
86	5	,, ,, 25	C	20	$\frac{3}{8}$	—	42	372	56	993	50	1·2	—	—	

* See note, page 22. † See note, page 22. ‡ See note, page 22.

TABLE V.—(*continued.*)

Running Number.	Diagram.	Authority, Date, or Official Number.			Boiler Type.	Furnace Age.	Details of Furnace.						Probable Collapsing Pressure.	Mean Stresses on		Reported Scale on Furnace.*	* Remarks against Mr. Marten's cases are chiefly from M.S.U.A. Records. Unless otherwise recorded, vertical boilers have a vertical uptake, but no crown stays, and the crown is dished.
							Thickness.		Diameter.	Length.	Ratio.			Original Section.	Reduced Section.		
							Original. t	Reduced.	D	L	$\frac{D}{2t}$	$\frac{D}{L}$					
						Years.	In.	In.	In.	In.			Lbs.	Tons.	Tons.		
87	4, 7	Marten	1872	33	C	15	$\frac{1}{2}$*	$\frac{3}{8}b$*	42	480	42	960	45	0·9	1·1	—	Locally $\frac{3}{8}$in.; very brittle iron.
88	4	,,	,,	41	C	—	$\frac{7}{16}$	—	40	288	46	680	45	0·9	—	—	No information, M.S.U.A.
89	4	,,	,,	59	C	23	$\frac{3}{8}$	—	33	288	44	795	40	0·8	—	—	No information, M.S.U.A.
90	6, 7	,,	,,	65	C	17	$\frac{5}{16}f$*	$\frac{5}{16}f$*	42	360	61	1,050	46*	1·3	1·3	—	Various plate thicknesses; not short of water.
91	5, 7	,,	1873	12	C	11*	$\frac{3}{8}$	$\frac{3}{8}$*	42	363	56	969	45*	1·1	1·1	$\frac{3}{16}$	Possibly higher pressure; engine stopped.
92	5—	,,	,,	49	C	—	$\frac{7}{16}$	$\frac{7}{16}$*	48	396	55	907	42	1·0	1·0	—	Engine was stopped 25 minutes earlier.
93	6, 8	,,	,,	52	L	Very old*	$\frac{1}{4}$*	$\frac{1}{4}$	30	312	60	1,248	68	1·8	1·8	—	
94	5, 7	,,	,,	57	C	8*	$\frac{7}{16}$	$\frac{7}{16}$*	47	384	56	879	50	1·2	1·2	—	Stated short of water (?); engine at rest three hours.
95	—	,,	,,	76	C	10	$\frac{7}{16}$*	—	45	252	55	620	35*	0·9	—	—	Rent $\frac{1}{8}$in. local.
96	—	,,	1874	10	C	4*	$\frac{5}{16}f$*	$\frac{5}{16}f$*	41	319	55	851	40*	1·1	1·1	—	Badly repaired; seam rip; no gussets.
97*	11, 12	,,	,,	14	C	10	$\frac{3}{8}$	$\frac{3}{8}$*	34	336	45	896	35	0·7	0·7	—	8in. oval; repaired five years previously.
98	6, 7	,,	,,	16	C	6*	$\frac{3}{8}$	$\frac{3}{8}$*	38	324	51	865	60*	1·4	1·4	—	
99	6, 7	,,	,,	23	C	$5\frac{1}{4}$†*	$\frac{3}{8}b$*	$\frac{3}{8}b$*	45	342	62	950	58*	1·6	1·6	—	

* See note, page 22. † See note, page 22. See note, page 22.

TABLE V.—(*continued.*)

Running Number.	Diagram.	Authority, Date, or Official Number.			Boiler Type.	Furnace Age.	Details of Furnace. Thickness. Original. t	Thickness. Reduced.	Diameter. D	Length. L	Ratio. $\frac{D}{2t}$	Ratio. $\frac{D}{L}$	Probable Collapsing Pressure.	Mean Stresses on Original Section.	Mean Stresses on Reduced Section.	Reported Scale on Furnace.	* Remarks against Mr. Marten's cases are chiefly from M.S.U.A. Records. Unless otherwise recorded, vertical boilers have a vertical uptake, but no crown stays, and the crown is dished.
						Years.	In.	In.	In.	In.			Lbs.	Tons.	Tons.		
100	11, 12	Marten	1874	25	C	12*	$\frac{3}{8}$	$\frac{3}{8}$*	42	360	56	960	75*	1·9	1·9	Thin	Furnace-top said to be flat; strengthening rings had been removed.
101	5	,,	,,	29	C	20*	$\frac{3}{8}$*	—	36	351	48	936	45	1·1	—	—	Patched along fire-line.
102	11, 12	,,	,,	32	L	18*	$\frac{7}{16}$*	$\frac{7}{16}$*	41	312	47	832	30*	0·6	0·6		Said to have been oval; not short of water.
103	6, 7	,,	,,	39	C	22*	$\frac{3}{8}$	$\frac{3}{8}b$*	42	264	56	704	55	1·4	1·4	—	Rent $\frac{5}{16}$ local; bad iron.
104*	6, 7	,,	,,	43	C	2*	$\frac{3}{8}$	$\frac{3}{8}$*	33	360	44	960	78	1·5	1·5	—	78lbs., includes bricks on lever.
105*	11, 12	,,	,,	50	C	22*	$\frac{3}{8}$	$\frac{11}{32}$*	34	384	45	1,025	63	1·3	1·4	$\frac{1}{16}$	2in. oval; possibly short of water.
106*	4	,,	,,	55	C	15	$\frac{13}{32}$	—	47	458	58	1,128	35	0·9	—	—	Much reduced thickness; not short of water.
107	6, 7	,,	1875	53	L	8*	$\frac{3}{8}$	$\frac{3}{8}$*	34	284	45	758	68	1·4	1·4	$\frac{1}{8}$	
108*	—	,,	,,	66	C	15	$\frac{5}{16}$*	—	30	288	48	922	86*	1·8	—	—	86lbs., includes bricks on lever; end plates badly stayed.
109	—	,,	1876	10	L	15*	$\frac{7}{16}$*	—	33	348	38	795	70*	1·2	—	—	70lbs., includes bricks on lever.
110*	5, 7	,,	,,	28	C	—	$\frac{3}{8}$	$\frac{1}{4}$	42	264	56	705	40	1·0	1·5		Recent repairs $\frac{1}{4}$in. thick.
111*	4	,,	1877	19	C	Very old*	$\frac{3}{8}$	$\frac{3}{8}$*	36	180	48	480	35	0·7	—	—	Safety-valve in order.
112*	4, 7	,,	,,	20	C	—	$\frac{7}{16}$	$\frac{5}{16}$	43	396	49	906	40	0·9	2·1	—	

* See note, page 22.

† See note, page 22.

‡ See note, page 22.

TABLE V.—(*continued.*)

Running Number.	Diagram.	Authority, Date, or Official Number.	Boiler Type.	Furnace Age.	Details of Furnace.						Probable Collapsing Pressure.	Mean Stresses on		Reported Scale on Furnace.*	* Remarks against Mr. Marten's cases are chiefly from M.S.U.A. Records. Unless otherwise recorded, vertical boilers have a vertical uptake, but no crown stays, and the crown is dished.
					Thickness.		Diameter.	Length.	Ratio.			Original Section.	Reduced Section.		
					Original. t	Reduced.	D	L	$\frac{D}{2t}$	$\frac{D}{L}$					
				Years.	In.	In.	In.	In.			Lbs.	Tons.	Tons.		
113		Marten 1877	22	C	1*	$\frac{11}{32}$	$\frac{11}{32}$*	36	312	52	907	56*	1·3	1·3	—	Possibly overheating.
114	—	,, ,,	26	C	4	$\frac{3}{8}$	—	31	240	41	640	103	1·1	—	—	Badly repaired.
115	5	,, ,,	32	C	10*	$\frac{3}{8}$	—	42	208*	56	545	44	1·1	—	—	Corroded.
116*	4, 7	,, 1878	7	C	20†*	$\frac{7}{16}$	$\frac{11}{32}$*	48	432	55	990	35	0·8	1·1	—	Not short of water.
117	11	,, ,,	10	L	6	$\frac{5}{16}$*	—	35	288	56	922	50	1·2	—	—	$1\frac{3}{4}$in. oval.
118	11, 12	,, ,,	16	L	23	$\frac{3}{8}$	$\frac{3}{8}$*	36	240	48	640	66	1·4	1·4	—	Distorted; ring seams fractured.
119*	4, 8	,, ,,	34	C	—	$\frac{5}{16}$	$\frac{1}{8}$	24	138	38	440	30	0·5	2·0	—	
120	6, 9	Board of Trade No.	4	V	—	$\frac{3}{8}$	$\frac{1}{4}$	46	75	61	200	70	1·9	2·9	—	
121	4, 7	,, ,,	63	C	30	$\frac{7}{16}$	$\frac{3}{16}$	39½	303	45	690	30	0·7	1·6	—	
122	—	,, ,,	73	V	14	$\frac{9}{32}$	$\frac{3}{32}$	29	42	51	149	50	1·1	3·4	—	
123	—	,, ,,	79	C	9	$\frac{1}{2}$	$\frac{1}{8}$	48	312	48	624	40	0·9	3·4	—	
124	11, 12	,, ,,	97	C	—	$\frac{7}{16}$	$\frac{1}{4}$	33	150	38	343	30	0·5	0·9	—	9in. oval.

* See note, page 22. † See note, page 22. ‡ See note, page 22.

TABLE V.—(*continued.*)

Running Number.	Diagram.	Authority, Date, or Official Number.	Boiler Type.	Furnace Age.	Details of Furnace. Thickness. Original. t	Thickness. Reduced.	Diameter. D	Length. L	Ratio. $\frac{D}{2t}$	Ratio. $\frac{D}{L}$	Probable Collapsing Pressure.	Mean Stresses on Original Section.	Mean Stresses on Reduced Section.	Reported Scale on Furnace.*	* Remarks against Mr. Marten's cases are chiefly from M.S.U.A. Records. Unless otherwise recorded, vertical boilers have a vertical uptake, but no crown stays, and the crown is dished.
				Years.	In.	In.	In.	In.			Lbs.	Tons.	Tons.		
125	4, 7	Board of Trade } No. 107	V	$15\frac{+}{4}$	$\frac{5}{8}$	$\frac{3}{16}$	35	44	47	117	40	0·8	1·7	—	One cross tube.
126	6, 9	,, ,, 115	V	18	$\frac{5}{8}$	$\frac{3}{16}$	35	66	47	175	70	1·5	2·9	—	No cross tube; no uptake.
127	5, 9	,, ,, 160	V	—	$\frac{5}{16}$	$\frac{1}{8}$	29	36	46	115	60	1·2	3·1	—	Two cross tubes.
128	4, 8	,, ,, 172	V	—	$\frac{1}{4}$	$\frac{3}{32}$	$25\frac{1}{2}$	33	41	132	37	0·7	2·2	—	One cross tube; wide conical uptake.
129	—	,, ,, 177	V	—	$\frac{3}{8}$	$\frac{1}{8}$	25	39	33	105	30	0·4	1·3	—	No cross tubes.
130	11, 12	,, ,, 214	V	5	$\frac{3}{8}$	$\frac{11}{32}$	40	66	53	176	68	1·6	1·8	—	Oval; bulged previously; two cross tubes.
131	11, 12	,, ,, 218	L	5	$\frac{13}{32}$	$\frac{13}{32}$	33	354	41	868	60	1·1	1·1	Floury Deposit	Oval; bulged previously.
132	6	,, ,, 219	V	17	$\frac{3}{8}$	$\frac{1}{4}b$	$50\frac{1}{2}$	34	67	91†	57	1·7	2·7	—	One pair cross tubes; spherical top.
133	4, —	,, ,, 230	C	18	$\frac{3}{8}$	$\frac{5}{16}$	30	250	40	665†	45	0·8	1·0	—	Ends in a cone; was tested previously by hydraulic pressure.
134	10	,, ,, 250	C	18	$\frac{3}{8}$	$\frac{5}{16}$	30	250	40	665†	90H	1·6	1·9	—	This is the hydraulic test referred to.
135	6, 9	,, ,, 257	V	13	$\frac{3}{8}$	$\frac{1}{4}$	47	77	62	206	107	3·0	4·5	—	Two cross tubes; flat crown.
136	5, 7	,, ,, 260	Chimney Boiler.	24	$\frac{3}{8}$	$\frac{1}{4}$	39	168	52	208†	49	1·1	1·7	—	Ends in a cone.

* See note, page 22.

† See note, page 22.

‡ See note, page 22.

TABLE V.—(*continued.*)

Running Number.	Diagram.	Authority, Date, or Official Number.	Boiler Type.	Furnace Age.	Details of Furnace.						Probable Collapsing Pressure.	Mean Stresses on		Reported Scale on Furnace.*	* Remarks against Mr. Marten's cases are chiefly from M.S.U.A. Records. Unless otherwise recorded, vertical boilers have a vertical uptake, but no crown stays, and the crown is dished.
					Thickness.		Diameter.	Length.	Ratio.			Original Section.	Reduced Section.		
					Original. t	Reduced.	D	L	$\frac{D}{2t}$	$\frac{D}{L}$					
				Years.	In.	In.	In.	In.			Lbs.	Tons.	Tons.		
137	5, 8	Board of Trade No. 267	V	13	$\frac{5}{16}$	$\frac{5}{32}$	$25\frac{1}{2}$	54	41	173	68	1·2	2·5	—	Field tubes from dished crown; no waterspace stays; recently tested by steam 80lbs.
138	6, 9	,, ,,	V	$14\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{16}$ *f*	$30\frac{1}{2}$	50	49	160	90	2·0	3·0	—	Field tubes from flat crown; $\frac{7}{16}$in. thick; bulged down; no uptake.
139	5, 8	,, ,,	V	6	$\frac{5}{16}$	$\frac{3}{16}$	$31\frac{1}{2}$	46	49	205	50	1·1	2·2	—	18 months; previously tested by hydraulic pressure.
140	10	,, ,,	V	$4\frac{1}{2}$	$\frac{5}{16}$	$\frac{3}{16}$	$31\frac{1}{2}$	46	49	205	100H	2·2	4·4	—	This is the hydraulic test referred to.
141	—	,, ,,	V	$7\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{16}$	43	60	57	160	40	1·0	2·0	—	No cross tubes; primary fracture in crown near uptake.
142	5, 7	,, ,,	C	$8\frac{1}{4}$	$\frac{5}{16}$	$\frac{1}{4}$	35	177	56	564	50	1·9	1·6	—	
143	6, 9	,, ,,	V	$20\frac{1}{4}$	$\frac{5}{16}$	$\frac{5}{32}$	31	37	50	118	87	1·9	3·9	—	Two cross tubes.
144	11, 12	,, ,,	C	$6\frac{1}{4}$	$\frac{7}{16}$	$\frac{7}{16}$	42	387	48	886	52	1·1	1·1	—	$1\frac{1}{4}$in. oval at front end.
145	11, 12	,, ,,	C	23	$\frac{3}{8}$	$\frac{5}{16}$	33	216	44	577	71	1·4	1·7	—	$\frac{3}{4}$in. oval at front; 2in. oval at back end; mean $1\frac{3}{8}$in.
146	5, 8	,, ,,	V	$12\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{16}$	30	54	40	144	70	1·2	2·5	—	Two cross tubes; flat crown.
147	4, —	,, ,,	L	19	$\frac{25}{64}$	$\frac{25}{64}$	30	274	38	693	50	0·8	0·8	Scale	Hydraulic test previous day.
148	10	,, ,,	L	19	$\frac{25}{64}$	$\frac{25}{64}$	30	271	38	693	95H	1·6	1·6	—	This is the hydraulic test referred to.

* See note, page 22.

; See note, page 22.

TABLE V. (*continued.*)

Running Number	Diagram.	Authority, Date, or Official Number.	Boiler Type.	Furnace Age.	Details of Furnace. Thickness. Original. t	Thickness. Reduced.	Diameter. D	Length. L	Ratio. $\frac{D}{2t}$	Ratio. $\frac{D}{L}$	Probable Collapsing Pressure.	Mean Stresses on Original Section.	Mean Stresses on Reduced Section.	Reported Scale on Furnace.	Remarks
				Years.	In.	In.	In.	In.			Lbs.	Tons.	Tons.		
149		Board of Trade } No. 358	V	10	$\frac{3}{8}$	$\frac{1}{8}$	36	72	48	192	52	1·1	3·3	—	Very conical; 36in. diam. at bottom; three cross tubes.
150	6, 9	,, ,, 363	V	3	$\frac{1}{2}$	$\frac{1}{2}$	69	108	69	157	120	3·7	3·7	—	Four cross tubes; crown stays; bulged close to all the vertical stays.
151	—	,, ,, 371	V	17	$\frac{3}{8}$	$\frac{1}{8}$	38	46	51	123	50	1·1	3·4	—	Two cross tubes; crown stays.
152	—	,, ,, 394	V	11†	$\frac{3}{8}$	$\frac{1}{8}$	42	59	56	241†	40	1·0	3·0	—	No cross tubes; spherical top.
153	—	,, ,, 396	C	10	$\frac{3}{8}$	—	36	421	48	112	47	1·0	—	—	Rent $\frac{1}{16}$in.; local.
154	11, 12	,, ,, 428	Navy	5†	$\frac{3}{8}$	$\frac{1}{4}$	24½	30	33	80	50	0·7	1·1	—	5in. oval; local corrosion.
155	5, 8	,, ,, 438	C	15	$\frac{3}{8}$	$\frac{1}{4}$	33	153	44	408	60	1·2	1·8	—	
156	4, 8	,, ,, 442	V	13	$\frac{5}{16}$	$\frac{1}{8}$	25	39	40	125	40	0·7	1·8	—	No cross tubes; flat crown.
157	6, 8	,, ,, 469	V	14†	$\frac{5}{16}$	$\frac{1}{4}$	36	60	58	192	60	1·5	1·9	—	One cross tube.
158	4, 7	,, ,, 521	C	10	$\frac{7}{16}$	$\frac{5}{16}$	43½	363	50	968	40	0·9	1·2	—	
159	—	,, ,, 524	V	23	$\frac{5}{16}$	$\frac{5}{32}$	28	48	45	153	20	0·4	1·3	—	Field tubes from crown; no crown stays.
160	6, 7	,, ,, 547	C	15	$\frac{3}{8}$	$\frac{3}{8}$	36	364	48	968	60	1·3	1·3	—	

‘ Remarks against Mr. Marten’s cases are chiefly from M.S.U.A. Records. Unless otherwise recorded, vertical boilers have a vertical uptake, but no crown stays, and the crown is dished.

* See note, page 22.

† See note, page 22.

‡ See note, page 22.

TABLE V. (*continued*).

Running Number.	Diagram.	Authority, Date, or Official Number.	Boiler Type.	Furnace Age.	Details of Furnace.						Probable Collapsing Pressure.	Mean Stresses on		Reported Scale on Furnace.	Remarks against Mr. Marten's cases are chiefly from M.S.U.A. Records. Unless otherwise recorded, vertical boilers have a vertical uptake, but no crown stays, and the crown is dished.
					Thickness.		Diameter.	Length.	Ratio.			Original Section.	Reduced Section.		
					Original. t	Reduced.	D	L	$\frac{D}{2t}$	$\frac{D}{L}$					
				Years.	In.	In.	In.	In			Lbs.	Tons.	Tons.		
161	4, 7	Board of Trade No. 551	V	12	$\frac{1}{4}$	$\frac{1}{8}$	24	38	48	152	40	0·9	1·7	—	No cross tubes; small tubes to boiler crown.
162	6, 7	,, ,, 601	L	0	$\frac{3}{8}$	$\frac{3}{8}$	36	204	48	544	70	1·5	1·5	—	
163	11, 12	,, ,, 619	C	1	$\frac{3}{8}$	$\frac{3}{8}$	39	196	52	523	74	1·7	1·7	—	$1\frac{1}{2}$in. oval.*
164	5, 9	,, ,, 671	V	—	$\frac{3}{8}$	$\frac{5}{32}$	40	46	53	123	50	1·2	2·9	—	No cross tubes.
165	6, 8	,, ,, 732	C	40	$\frac{1}{2}$	$\frac{3}{8}$	42	300	42	600	75	1·4	1·9	—	Said to have been truly cylindrical.
166	5, 8	,, ,, 747	V	20	$\frac{3}{8}$	$\frac{1}{4}$	42	66	56	176	50	1·2	1·9	—	Two cross tubes.
167	5, 7	,, ,, 859	C	12	$\frac{3}{8}$	$\frac{5}{16}$	36	288	48	767	50	1·1	1·3	—	
168	5, 7	,, ,, 871	C	27	$\frac{3}{8}$	$\frac{5}{16}$	21	108	28	288	84	1·1	1·3	—	
169	—	,, ,, 888	V	15	$\frac{3}{8}$	$\frac{1}{8}$	30	45	40	120	60	1·1	3·2	—	Two cross tubes.
170	—	,, ,, 921	C	35	$\frac{3}{8}$	$\frac{1}{16}$	20	66	27	176†	30	0·4	2·1	—	One end conical.
171	5, 8	,, ,, 983	V	12	$\frac{3}{8}$	$\frac{1}{4}$	28	34	37	91	60	1·0	2·0	—	No cross tubes; small tubes and stay to boiler crown.
172	6, 8	,, ,, 1032	V	10	$\frac{3}{8}$	$\frac{1}{4}$	42	60	56	160	60	1·5	2·2	—	Steel; two cross tubes welded to furnace.

* See note, page 22.

† See note, page 22.

TABLE VI.

THE DETAILS OF THE OVAL AND DEFORMED FURNACES IN TABLE II. ARE REPEATED HERE.
SEE ALSO DIAGRAMS 11 AND 12.

Running Number.	Diagram.	Authority, Date, or Official Number.			Boiler Type.	Furnace Age.	Details of Furnace. Thickness. Original. t	Thickness. Reduced.	Diameter. D	Length. L	Ratio. $\frac{D}{2t}$	Ratio. $\frac{D}{L}$	Probable Collapsing Pressure.	Mean Stresses on Original Section.	Mean Stresses on Reduced Section.	Reported Scale on Furnace.*	* Remarks against Mr. Marten's cases are chiefly from M.S.U.A. Records. Unless otherwise recorded, vertical boilers have a vertical uptake, but no crown stays, and the crown is dished.
						Years.	In.	In.	In.	In.			Lbs.	Tons.	Tons.		
57	11	Marten	1866	20	C	—	$\frac{7}{16}$	—	48	360	55	825	43	1·0	—	—	Oval; pressure probably exceeded.
68*	11	,,	1868	42	C	$4\frac{1}{4}$*	$\frac{5}{16}$*	—	33	180	53	575*	50	1·2	—	—	4in. oval at front end; intermediate cone; back end 24in. collapsed.
77*	11, 12	,,	1870	25	C	$2\frac{1}{4}$*	$\frac{1}{4}$*	$\frac{1}{4}$*	36	252	72	1008	40	1·3	1·3	$\frac{1}{8}$	Oval and cracked; sometimes extra load on lever.
97*	11, 12	,,	1874	14	C	10	$\frac{3}{8}$	$\frac{3}{8}$*	34	336	45	896	35	0·7	0·7	—	8in. oval; repaired five years previously.
100	11, 12	,,	,,	25	C	12*	$\frac{3}{8}$	$\frac{3}{8}$*	42	360	56	960	75*	1·9	1·9	Thin.	Furnace top said to be flat.
102	11, 12	,,	,,	32	L	18*	$\frac{7}{16}$*	$\frac{7}{16}$*	41	312	47	832	30*	0·6	0·6	—	Said to have been oval; not short of water.
105*	11, 12	,,	,,	50	C	22*	$\frac{3}{8}$	$\frac{11}{32}$*	34	384	45	1025	63	1·3	1·4	$\frac{1}{16}$	2in. oval; possibly short of water.
117	11	,,	1878	10	L	6	$\frac{5}{16}$*	—	35	288	56	922	50	1·2	—	—	$1\frac{3}{4}$in. oval.
118	11, 12	,,	,,	16	L	23	$\frac{3}{8}$	$\frac{3}{8}$*	36	240	48	640	66	1·4	1·4	—	Distorted; ring seams fractured.
124	11, 12	Board of Trade	No.	97	C	—	$\frac{7}{16}$	$\frac{1}{4}$	33	150	38	343	30	0·5	0·9	—	9in. oval.

* See note, page 22.

† See note, page 22.

TABLE VI.—(*continued.*)

Running Number.	Diagram.	Authority, Date, or Official Number.	Boiler Type.	Furnace Age.	Details of Furnace.						Probable Collapsing Pressure.	Mean Stresses on		Reported Scale on Furnace.*	* Remarks against Mr. Marten's cases are chiefly from M.S.U.A. Records. Unless otherwise recorded, vertical boilers have a vertical uptake, but no crown stays, and the crown is dished.
					Thickness.		Diameter.	Length.	Ratio.			Original Section.	Reduced Section.		
					Original. t	Reduced.	D	L	$\frac{D}{2t}$	$\frac{D}{L}$					
				Years.	In.	In.	In.	In.			Lbs.	Tons.	Tons.		
130	11, 12	Board of Trade No. 214	V	5	$\frac{3}{8}$	$\frac{11}{32}$	40	66	53	176	68	1·6	1·8	—	Oval; bulged previously; two cross tubes.
131	11, 12	,, ,, 218	L	5	$\frac{13}{32}$	$\frac{13}{32}$	33	354	41	868	60	1·1	1·1	Floury Deposit	Oval; bulged previously.
144	11, 12	,, ,, 326	C	$6\frac{1}{4}$	$\frac{7}{16}$	$\frac{7}{16}$	42	387	48	886	52	1·1	1·1	—	$1\frac{1}{4}$in. oval at front end.
145	11, 12	,, ,, 331	C	23	$\frac{3}{8}$	$\frac{5}{16}$	33	216	44	577	71	1·4	1·7	—	$\frac{3}{4}$in. oval at front; 2in. oval at back end; mean $1\frac{3}{8}$in.
144	11, 12	,, ,, 428	Navy	$5\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	$24\frac{1}{2}$	30	33	80	50	0·7	1·1	—	5in. oval; local corrosion.
163	11, 12	,, ,, 619	C	1	$\frac{3}{8}$	$\frac{3}{8}$	39	196	52	523	74	1·7	1·7	—	$1\frac{1}{2}$in. oval.*

* See note, page 22.

‡ See note, page 22.

TABLE VII.

OVAL FURNACES AT WORK. DETAILS COLLECTED BY THE INSPECTORS OF THE MANCHESTER STEAM USERS' ASSOCIATION.

NONE OF THESE FURNACES HAVE COLLAPSED. *See Diagrams 13 and 14.*

Running Number	Boiler Type.	Furnace Age.	Thickness. Original. t	Thickness. Estimated Reduced.	Diameter. D	Length. Total.	Length. Unsupported. L*	Ratio. $\frac{D}{2t}$	Ratio. $\frac{L}{t}$	Customary Working Pressure.	Mean Stress on Original Section.	Mean Stress on Reduced Section.	Oval.	Coal burnt per square foot of grate per hour.	Usual Scale.	REMARKS.
		Years.	In.	In.	In.	In.	In.			Lbs.	Tons.	Tons.	In.	Lbs.		
173	L	24	$\frac{7}{16}$	$\frac{5}{16}$	$31\frac{1}{4}$	263	60 *a*	36	137	45	0·7	1·0	$2\frac{1}{4}$	—	—	Much pitting.
174	L	22	$\frac{3}{8}$	$\frac{1}{4}$	$34\frac{1}{8}$	321	156 *c*	46	415	30	0·6	0·9	$1\frac{13}{16}$	12	Thick	Local drillings $\frac{5}{32}$in.
175	L	33	$\frac{3}{8}$	$\frac{5}{16}$	$29\frac{1}{4}$	240	48 *a*	39	128	60	1·0	1·2	$1\frac{3}{4}$	11	Grease	
176	C	Old	$\frac{5}{16}$	$\frac{1}{4}$	$27\frac{5}{8}$	122	122	44	390	30	0·6	0·7	$1\frac{3}{4}$	—	Medium	Local bulge 2in.
177	C	11	$\frac{3}{8}$	$\frac{3}{8}$	27	187	187	36	497	50	0·8	0·8	$1\frac{5}{8}$	13	Medium	This is a local bulge.
178	L	24	$\frac{3}{8}$	$\frac{1}{4}$	$20\frac{3}{4}$	192	66 *a*	28	176	48	0·6	0·9	$1\frac{1}{2}$	12	—	Severe corrosion.
179	L	44	$\frac{3}{8}$	$\frac{5}{16}$	$30\frac{5}{8}$	339	339	41	904	50	0·9	1·1	$1\frac{1}{2}$	15	Thick	Deep pittings.
180	L	26	$\frac{3}{8}$	$\frac{5}{16}$	$24\frac{1}{2}$	240	240	33	640	60	0·9	1·0	$1\frac{1}{2}$	22	—	Local bulge 2in.
181	L	10†	$\frac{7}{16}$	$\frac{5}{16}$	$32\frac{1}{4}$	360	360	37	822	50	0·8	1·1	$1\frac{1}{2}$		Thick	Much corrosion.

* NOTE.—*a* = angle iron ring; *b* = Bowling hoop; *c* = cross tubes *s* = bolt stay across diameter; *t* = T iron ring.

† This boiler is older than stated, having been bought second-hand.

TABLE VII.—(*continued.*)

Running Number.	Boiler Type.	Furnace Age.	Thickness. Original. t	Thickness. Estimated Reduced.	Diameter. D	Length. Total.	Length. Unsupported. L*	Ratio. $\frac{D}{2t}$	Ratio. $\frac{L}{t}$	Customary Working Pressure.	Mean Stress on Original Section.	Mean Stress on Reduced Section.	Oval.	Coal burnt per square foot of grate per hour	Usual Scale.	REMARKS.
		Years.	In.	In.	In.	In.	In.			Lbs.	Tons.	Tons.	In.	Lbs.		
182	C	27	$\frac{3}{8}$	$\frac{5}{16}$	$31\frac{3}{4}$	192	64 *c*	42	171	50	0·9	1·1	$1\frac{3}{8}$	12	Thick	
183	C	22	$\frac{3}{8}$	$\frac{5}{16}$	$25\frac{3}{4}$	120	60 *b*	34	160	65	1·0	1·2	$1\frac{3}{8}$	7	Medium	Plates roughened by corrosion.
184	L	25	$\frac{3}{8}$	$\frac{5}{16}$	$26\frac{5}{8}$	288	60 *a*	36	160	50	0·8	0·9	$1\frac{3}{8}$	18	Thin	
185	L	40	$\frac{7}{16}$	$\frac{3}{8}$	$31\frac{7}{8}$	338	338	36	771	50	0·8	1·0	$1\frac{1}{4}$	15	—	Plate pitted.
186	C	Old	$\frac{3}{8}$	—	$35\frac{7}{8}$	240	120 *a*	48	321	50	1·1	—	$1\frac{1}{4}$	—	—	First cross tube 100in. from front end.
187	C	Old	$\frac{3}{8}$	—	$27\frac{7}{8}$	180	90 *s*	37	480	60	1·0	—	$1\frac{1}{4}$	—	Thick	The bolt stay was fitted to reduce previous oval.
188	C	Old	$\frac{3}{8}$	$\frac{5}{16}$	$32\frac{3}{4}$	179	179	44	477	40	0·8	0·9	$1\frac{1}{4}$	12	Medium	
189	C	35	$\frac{11}{32}$	$\frac{1}{4}$	$27\frac{1}{8}$	135	135	39	392	50	0·9	1·2	$1\frac{1}{4}$	—	Thick & Loose	Pitting and general wasting.
190	L	19	$\frac{7}{16}$	$\frac{3}{8}$	32	288	171 *c*	37	391	50	0·8	1·0	$1\frac{3}{16}$	—	—	Plates roughened by corrosion.
191	L	43	$\frac{3}{8}$	$\frac{5}{16}$	$26\frac{1}{4}$	237	237	34	632	45	0·6	0·8	$1\frac{1}{8}$	9	Thin	Floury deposit.
192	C	33	$\frac{3}{8}$	$\frac{1}{4}$	$27\frac{1}{2}$	144	144	37	384	60	1·0	1·5	$1\frac{1}{8}$	—	—	Overheated 6 years previously.

a, *b*, *c*, *s*.—See notes page 31.

TABLE VII.—(*continued.*)

Running Number.	Boiler Type.	Furnace Age.	Thickness. Original. t	Thickness. Estimated Reduced.	Diameter. D	Length. Total.	Length. Unsupported. L*	Ratio. $\frac{D}{2t}$	Ratio. $\frac{L}{t}$	Customary Working Pressure.	Mean Stress on Original Section.	Mean Stress on Reduced Section	Oval.	Coal burnt per square foot of grate per hour.	Usual Scale.	REMARKS.
		Years.	In.	In.	In.	In.	In.			Lbs.	Tons.	Tons.	In.	Lbs.		
193	C	—	$\frac{3}{8}$	—	$32\frac{1}{8}$	204	$39\,t$	43	106	40	0·8	—	$1\frac{3}{16}$	—	—	Rarely at work.
194	L	33	$\frac{3}{8}$	$\frac{5}{16}$	28	310	310	37	826	45	0·7	0·9	1	—	—	
195	L	New	$\frac{3}{8}$	$\frac{3}{8}$	$28\frac{1}{2}$	228	228	38	607	40	0·7	0·7	1	8	Thin	
196	C	Old	$\frac{5}{16}$	$\frac{1}{4}$	23	96	96	37	256	60	1·0	1·2	1	10	—	Local bulge $1\frac{1}{2}$in.
197	C	31	$\frac{3}{8}$	$\frac{1}{4}$	$29\frac{1}{4}$	120	120	39	320	45	0·8	1·2	1	—	Thick	Plates roughened by corrosion.
198	L	16	$\frac{3}{8}$	$\frac{3}{8}$	$31\frac{1}{4}$	288	$72\,t$	46	92	50	1·0	1·0	$\frac{7}{8}$	7	—	
199	L	28	$\frac{7}{16}$	—	$31\frac{5}{8}$	339	$114\,b$	36	302	60	1·0	—	$\frac{7}{8}$	—	Thick	The back half of furnace is taper.
200	C	18†	$\frac{7}{16}$	$\frac{7}{16}$	$34\frac{3}{4}$	243	$72\,a$	40	164	50	0·9	0·9	$\frac{7}{8}$	14	Thin	
201	C	22	$\frac{5}{16}$	$\frac{1}{4}$	$28\frac{3}{4}$	144	144	46	460	45	0·9	1·2	$\frac{7}{8}$	—	Thin	
202	C	23†	$\frac{3}{8}$	$\frac{1}{4}$	$33\frac{7}{8}$	216	216	45	575	40	0·8	1·2	$\frac{3}{4}$	9	Thin	Scale formerly very thick; numerous pittings.

a, *b*, *t*, †.—See notes page 34.

EXPERIMENTAL HYDRAULIC TESTS.

DIAGRAM 1

HYDRAULIC TESTS SEE TABLE IV (STRESSES 10·2 TONS AND LESS)

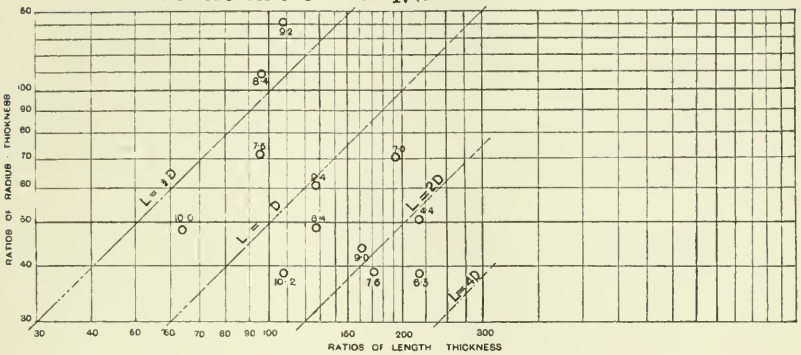


DIAGRAM 2

HYDRAULIC TESTS, SEE TABLE IV STRESSES 11·4 — 13·8 TONS)

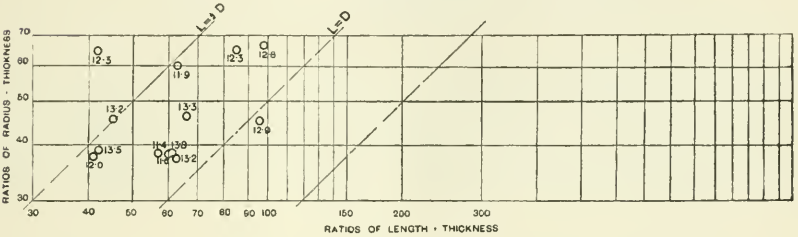
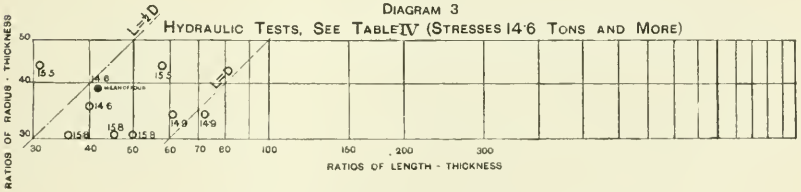


DIAGRAM 3

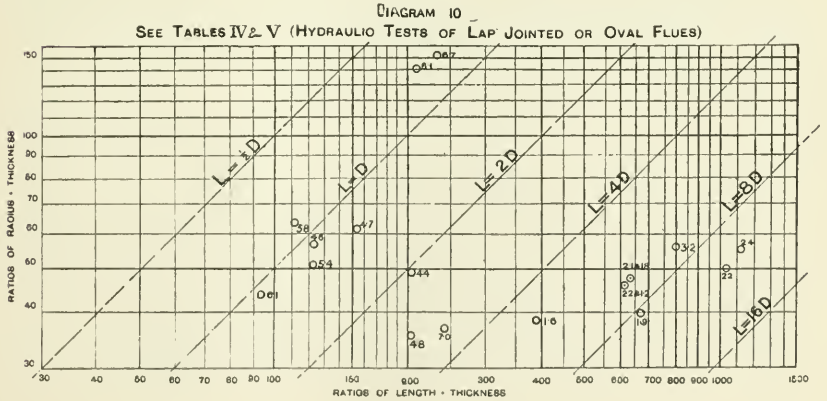
HYDRAULIC TESTS, SEE TABLE IV (STRESSES 14·6 TONS AND MORE)



HYDRAULIC TESTS OF BOILERS, &c.

DIAGRAM 10

SEE TABLES IV & V (HYDRAULIC TESTS OF LAP JOINTED OR OVAL FLUES)



COLLAPSES UNDER STEAM.

DIAGRAM 4

COLLAPSED FLUES, SEE TABLE V (STRESSES ON ORIGINAL THICKNESSES

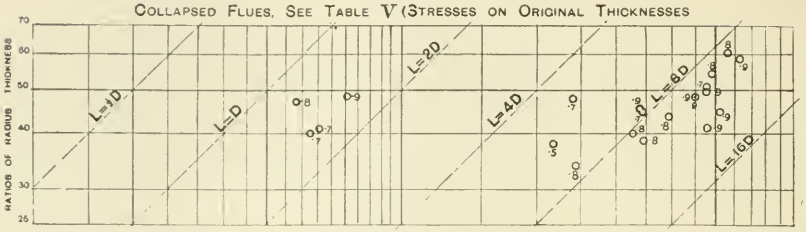


DIAGRAM 5

COLLAPSED FLUES, SEE TABLE V (STRESSES ON ORIGINAL THICKNESSES 10 – 12 TONS)

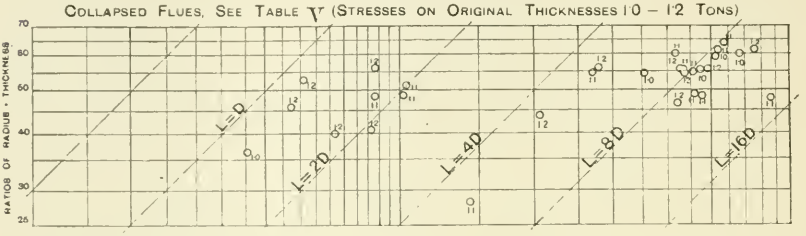


DIAGRAM 6

COLLAPSED FLUES, SEE TABLE V (STRESSES ON ORIGINAL THICKNESSES 13 TONS AND MORE)

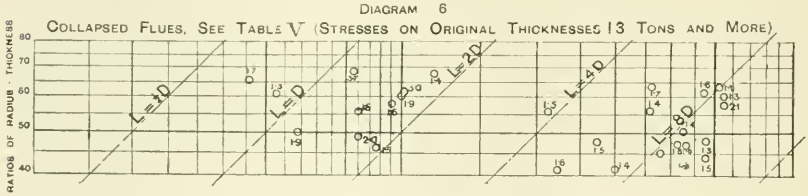


DIAGRAM 7

COLLAPSED FLUES, SEE TABLE V (STRESSES ON REDUCED THICKNESSES 11 TO 17 TONS)

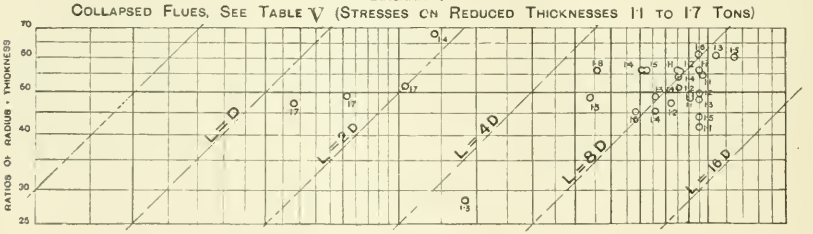


DIAGRAM 8

COLLAPSED FLUES, SEE TABLE V (STRESSES ON REDUCED THICKNESSES 18 TO 25 TONS)

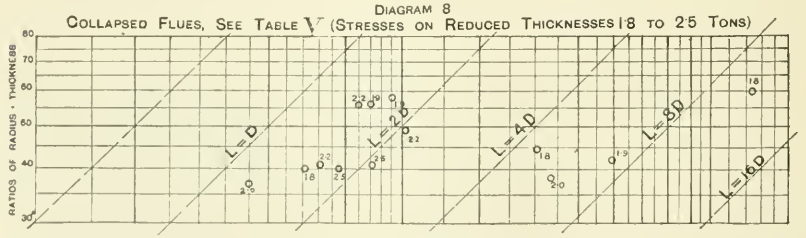
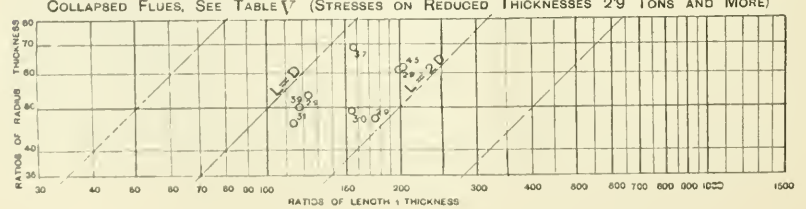


DIAGRAM 9

COLLAPSED FLUES, SEE TABLE V (STRESSES ON REDUCED THICKNESSES 29 TONS AND MORE)



OVAL FLUES (COLLAPSED).

DIAGRAM 11

COLLAPSED OVAL FLUES, SEE TABLES V &VI (STRESSES ON ORIGINAL THICKNESSES)

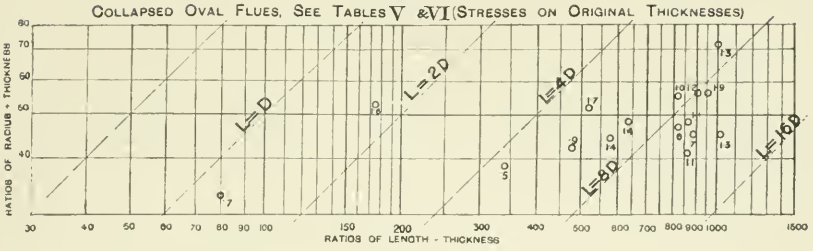
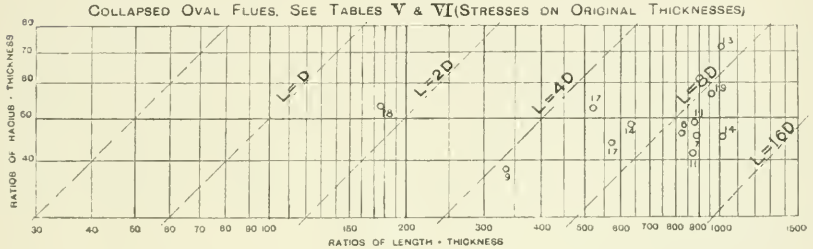


DIAGRAM 12

COLLAPSED OVAL FLUES, SEE TABLES V & VI (STRESSES ON ORIGINAL THICKNESSES)



OVAL FLUES (AT WORK).

DIAGRAM 13

OVAL FURNACES AT WORK, SEE TABLE VII (STRESSES ON ORIGINAL THICKNESSES)

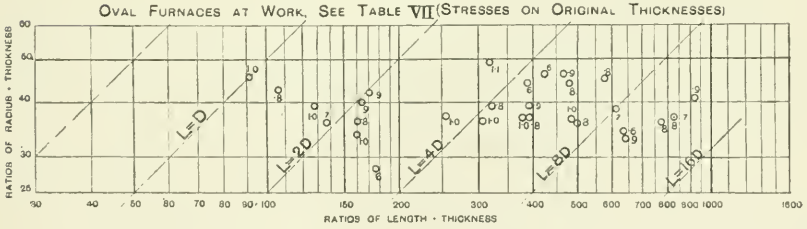
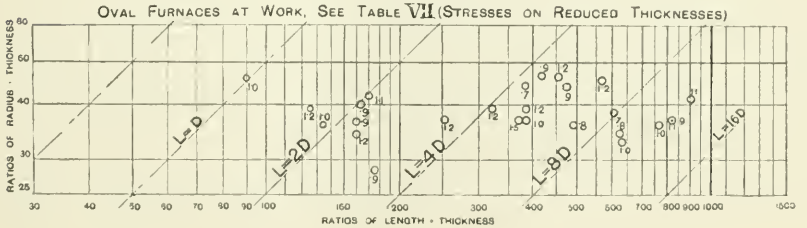


DIAGRAM 14

OVAL FURNACES AT WORK, SEE TABLE VII (STRESSES ON REDUCED THICKNESSES)



NEW BOILERS.

Inquiries are frequently made as regards the best type of boiler for a particular service. It is therefore well to point out what are the most general demands on a boiler and what boilers are best suited for these purposes.

In colliery districts, where land and coal are cheap, the general demand is for a boiler of the cheapest type provided it requires few repairs. There can be no doubt that the Cornish and Lancashire boilers of medium pressure best fulfil these conditions.

If the boilers are required for intermittent heavy steam supply, as, for instance, for winding engines at mines, boilers with large water volumes are desirable, and in such cases the Lancashire and Cornish type are the best. For the sake of the large water volume required, the furnaces should be kept relatively small and placed low. Water-tube boilers with their small water volumes would be quite out of place here, but sometimes they have to be used in mountainous districts because of the transport difficulties.

In places where coal is dear, the boilers will have to be economical, and here again the Lancashire and Cornish boilers give satisfaction, if they are not overworked, and especially if they are provided with economisers. This arrangement is therefore largely, in fact almost universally, adopted in factories outside towns.

The floor space occupied by such installations makes them very expensive in the centres of large towns, and recourse is had to various types of boilers of smaller dimensions; but these are mostly less economical than the above.

Amongst these may be mentioned the vertical type. It is only fit for small power, but it has this advantage: that much power is developed per square foot of floor space, as the grate surface is nearly as large as the space on which the boiler stands. The ordinary type is very wasteful as regards fuel, but somewhat more economical ones are the Field boilers, Cochrane boilers, Blake boilers, &c.

Locomotive or portable boilers are also sometimes used, particularly where the power required is not great; but these boilers, on account of their cramped construction, cannot be easily examined nor kept in order, and on account of their small water volume, and also because of the firebox crowns being so near the water level, these boilers require most careful watching, so that, in spite of all precautions, they frequently get into trouble and compel a stoppage of the works. They are light for the work which can be got out of them. They were once used in the Navy for special purposes, but have been superseded by express (small tube) water-tube boilers, which are very light and contain very little water.

Water-tube boilers have of late been largely used in towns where land is costly. Steam can be got up in them very quickly, say within

one hour's time after lighting fires. This is an advantage in electric light stations, where at regular periods, say at sunset, much steam is required; but these boilers cannot raise steam sufficiently quickly to meet the sudden fogs which occur in most English towns; they have therefore, in this country, to be kept under banked fires night and day, as would also have to be done with boilers having more water volume. As the reserve power is in the fire and not in the water, it is exceedingly difficult to keep the steam and the water level steady in these boilers, and they have to be most carefully watched. Variations in the engine power or in the firing affect them very much. The water for these boilers has also to be exceedingly pure, and they should never be put down without a water purifier with which the mineral matter is removed *before* the water enters the boiler. If the engines have surface condensers, grease filters are absolutely necessary. Scale or grease, which is injurious to all boilers, is fatal to these. About twenty or thirty years ago marine engineers passed through a very sad and costly experience with water-tube boilers, which taught them that they could not be worked except with pure water. The recent re-introduction of these boilers at sea was only possible after the perfecting of feed filters and distillers (evaporators) which remove all grease and mineral matter. It would be regrettable if steam users ashore were to overlook this costly lesson and were to pay for it over again. It is pointed out by the makers of these boilers that they can be very speedily repaired. Experience seems to show that repairs are frequently necessary.

Marine boilers occupy in many respects a position between Lancashire boilers and water-tube boilers. If not overworked they are very economical. The floor space occupied by them is much less than that required for Lancashire boilers. For medium sizes it is about equal to that required for the customary water-tube boilers, and when made of large diameter they occupy relatively less space, but in that case they offer such serious obstacles to transport overland that they can only be set up in seaport towns. The small sizes are much used in the Colonies and also in towns where space is valuable.

Dry-backed boilers are similar in shape to marine boilers, except that there are no internal combustion chambers. They are, therefore, cheaper, and they occupy little more space than these; but very large boilers of this type do not seem to have been built.

The following short summary indicates the relative advantages of the various types for special purposes. Water-tube boilers have been omitted because of the diversity of type; the necessary details can easily be obtained from the makers. Generally speaking, the simplest comparison which can be made before deciding on a boiler is to add together the interest on the first cost of the boiler and housing, the ground rent, coal, and attendance, and to divide this sum by the amount of water to be evaporated.

TABLE VIII.

Comparison of Boiler Types. Working Pressure 150lbs.				
Boiler Type.	Lancashire including Economiser	Dry Back.	Marine.	Marine.
Boiler Dimensions.....feet	8×30	$8\frac{1}{2}\times14$	$10\frac{1}{2}\times9$	14×10
Floor Space, including a 10ft. stoke-hold.....feet	11×52 572	$11\frac{1}{2}\times27\frac{1}{2}$ 316	$11\times19\frac{1}{4}$ 212	$14\frac{1}{2}\times20\frac{1}{4}$ 295
Approx. Cost including setting .....£	750	570	700	1,300
Grate Surface.....feet	40	33	40	60
Heating Surface.....feet	960 (boiler)	1,316	1,000	1,950
Coal per 56 hours.....tons	30	30	30	60
Water Evaporated per hour.....lbs.	7,500	7,000	7,000	14,000
Boiler Weight.....tons	20 (boiler)	$17\frac{3}{4}$	15	29
Water Weights.....tons	19	12	11	22

The above comparisons have been made to assist members to decide upon any particular type of boiler; but it will, of course, always be to their advantage to consult this Association. Up to the end of last year we had designed and inspected during construction 2,531 boilers. Of these, 1,683 are being annually inspected and guaranteed by this Association, so that our experience is very complete. The numbers of each type are given in the following table :—

TABLE IX.

Boiler Type.	Number of Boilers.
Lancashire	1,171
Cornish	170
Vertical	156
Locomotive and Portable	70
Marine	93
Externally Fired	11
Water-tube	12
Total.....	1,683

It will thus be seen that, as all these boilers have been watched by us ever since they were built, as well as many others, this Association is in a position to recommend designs which will give real satisfaction.

On account of the success of these boilers, steam users frequently specify that their boilers are to be built to our requirements, but frequently they omit to say that they have to be inspected by us. As we are not called in, they cannot therefore be sure that they are obtaining the boilers they had wished for. A more satisfactory arrangement is for them to place the matter in our hands, letting us draw up the specification and see the boiler built. The fee for this service is low. In any case it

should be clearly stated that the boiler is to be built under our inspection. Only then is it possible to be sure that the material and workmanship are up to our requirements. In cases when the boiler is not seen until after completion this will be stated on the Certificate, of which two are now issued as under :—

"Certificate (A) of New Steel Boiler. This is to Certify "that the Steel Boiler made by.....(No.....)
"for..... .....and described on the back hereof, has been "Specially Examined during Construction at the Maker's Works, and "found to have been built in accordance with the requirements of this "Association both as regards Dimensions, Material, and Workmanship. "The Boiler was satisfactorily tested by hydraulic pressure to.....lbs. "per square inch. The Boiler and its Fittings were found to be in a Good, "Efficient, and Safe Working Condition for the approved working "pressure of.....lbs. per square inch. Witness my hand,
"Mark on Boiler ....
"No.....A. Secretary. Chief Engineer.
"M.S.U.A. Test. Manchester Steam Users' Association, Manchester.
".....lbs.
"Date..... ....."

"Certificate (B) of test of New Steel Boiler. This is to "Certify that the Steel.....Boiler made by.....
"(No.....) for.....and described on the back "hereof, has been examined after completion at the Maker's Works by an "Inspector to this Association, and was tested in his presence by hydraulic "pressure to.....lbs. per square inch, with satisfactory results. Approved "working pressure.....lbs. per square inch.
"Mark on Boiler Witness my hand,
"No.....B. ....
"M.S.U.A. Test, Secretary. Chief Engineer.
".....lbs. Manchester Steam Users' Association, Manchester.
"Date....."

Note on back of Certificates. "Certificate (A) is issued when a boiler "and its fittings have been built to the satisfaction of, and in accordance "with, the specification drawn up or approved by this Association, and "which has been Specially Inspected during Construction, as follows: "Approving material, examining the plates when bent, when flanged, "when drilled, and when riveted; also examining the fittings and testing "the boiler by hydraulic pressure.

"Certificate (B) is issued when a boiler has been submitted for "inspection and hydraulic testing after completion if the hydraulic test "and the scantlings were then found satisfactory for the intended working "pressure."

Boilers which are of such a design as to be inaccessible after completion cannot obtain the Certificate (B). They should be examined during construction, and would then be eligible for Certificate (A).

It has been thought that a brief summary of the numbers and types of boilers under the care of this Association would be of interest. It is contained in the following table.

TABLE X.

Boiler Type	Total Number	Oldest Boiler	With Safety Valves			With Low Water Alarms				
			One	Two	Three	Floats Only	Fusible Plugs Only	Both	Alarms	None
Lancashire.....	3481	1850	427	2923	112	1685	621	1072	9	94
Cornish	1097	1845	548	517	25	138	726	133	11	89
Vertical	922	1868	529	367	7	15	359	13	5	530
Locomotive	548	1864	54	488	6	..	514	1	3	30
Marine.....	190	1865	21	167	2	..	4	..	1	185
Externally Fired.	167	1856	91	64	..	36	4	4	7	116
Water-tube.....	30	1873	13	11	..	..	..	..	..	30
Totals.....	6435	..	1684	4437	152	1874	2228	1293	36	1074

It will be noticed that some boilers are very old. They are being most carefully watched, but as they show no signs of weakness they are still allowed to be used. The experience as regards influence of time on the quality of iron boiler plates is that the furnace tubes apparently absorb the noxious gases from the fuel and deteriorate. Even Lowmoor iron furnaces lose their excellent flanging properties; they are then also rather brittle when cold. An interesting confirmation of this view was recently brought under my notice. A wrought-iron watermain which had been secured to the underside of a foot bridge over a railway station was, on being removed, found to be quite brittle just at that point where it was exposed to the fumes from the locomotives, which generally were brought to a standstill just under this pipe. The adjoining parts of the pipe were tough and good.

As regards boiler shell plates, their quality does not seem to be affected by time. It is, however, not certain whether different qualities do not behave differently in this respect.

The above table X. also shows to what extent safety appliances are fitted to boilers. Safety valves are, of course, imperative, except when boilers are used for heating purposes and are open to the atmosphere; but even in these cases safety valves are generally fitted. Some apparent discrepancies in the table are due to the fact that some boilers are fitted with combined low-water alarms and safety valves, and these have not been returned under safety valves.

Boilers with two or more safety valves are, of course, relatively safer than those with only one, and boilers with some sort of low-water alarm are safer than those without any.

Very few boilers of the Lancashire and Cornish type are not provided with low-water alarms of some sort. Experience shows that frictionless floats are really the safest contrivance with which to guard against low water; they invariably give warning, at least when the pressure is up; they only fail in those cases where the fire is lit without water in the

boiler. Fusible plugs are not so reliable; many cases of bulged furnaces occur in which the alloy fused either too late or not at all. It is also a great inconvenience for a mill to have to stop work every time that the water has temporarily fallen low, for such plugs cannot be renewed without entering the boiler. For this reason they should not be fitted to marine boilers, for in case of danger it is better to have a deformed boiler to work with than to have no steam power at all. All the water-tube boilers under our care are returned in Table X. as being without low-water alarms of any kind, but this year some have been fitted. On account of the small water reserve in these boilers, alarms are in some respects an inconvenience, in so far as they frequently give off loud warnings and let everybody know the state of the water level; on the other hand, these warnings are very necessary, for with the small water volume in these boilers it takes very little time to empty them. At sea, automatic feed pumps are now being used to regulate the supply, and where electricity is available this is doubtless a very effective and convenient arrangement.

For some types of boilers, particularly if the dimensions are small, no low-water alarms are used, but on land it is not advisable to do without them, because the water supply can easily get out of order without being noticed, more particularly as factory engines are stopped at least three times every twenty-four hours. At sea, where steaming is continuous and where surface condensers are used, the feed is of course practically the same as the amount of water evaporated, so that the average height of water in the boilers remains constant, and if only one boiler is used the feed hardly needs looking after. On the other hand, winch, and similar boilers, may suddenly have to supply much steam; the feed tank may have got empty or the pump may be out of order. If in such a case the gauge glass is choked, or if it is difficult to read, an accident is imminent. Such boilers should be provided with suitable alarms.

ENGINES.

One of the original objects of this Association was to give advice to our members as to the safety and efficiency of their engines, but it is only within comparatively recent years that our members have availed themselves of our services in this respect. At present there are about 250 engines which are periodically indicated and reported upon by our inspectors, and it is found that recommendations have frequently to be made as regards the setting of the valves which, when altered, results in economic advantages. Occasionally steam users ask us to examine their engines while being overhauled, but it would be to their advantage if this were done more regularly, say at intervals of four years or less. Flaws which might be developing in the crankshaft, cylinders, or flywheel could be detected on these occasions and put right in time.

NEW ENGINES.

The practice of having engines built under our inspection is increasing, particularly when they are intended for export. The certificates of this Association are readily accepted as evidence of the design, workmanship, and material.

ENGINE AND BOILER TRIALS.

Three economic tests were carried out last year. In each case the feed water measurements have been corrected every quarter of an hour to the original water level and steam pressure in the boiler. In the Astley Mill Trials, page 50, the condensation water and heat discharged were also measured.

Messrs. J. CROSSLEY & SONS, HALIFAX.

The engines were of the compound beam type, having two cylinders 39in. diameter and 3ft. 6in. stroke, and two cylinders 43⅜in. diameter and 7ft. stroke. These engines were supplied with steam from three Lancashire boilers of the dimensions given in the tables, and these boilers were cut off from the economisers. The necessary feed measuring tanks were fitted, and careful readings were taken every quarter of an hour. The trials lasted 7 hours on the first day, and 6¾ hours on the second day. The detailed results can be obtained from Diagrams 15 and 16, and the average results will be found in Table XII.

Dimensions of Boilers.

2 Lancashire Boilers, 7ft. 6in. diameter, 26ft. 9in. long, Heating Surface	1,920 sq. ft.
1 Lancashire Boiler, 7ft. 6in. diameter, 27ft. 0in. long, Heating Surface	970 sq. ft.
Total Heating Surface	2,890 sq. ft.
Grate Surface. 6 grates, 2ft. 11in. × 5ft. 0in....	87½ sq. ft.

Simplex Mechanical Stoker was used.

Fuel.

Coal of the same quality was used on both days. The average moisture in the coal was 3·91 per cent.

TABLE XI.

Chemical Analysis by Messrs. Crace, Calvert, & Thomson.

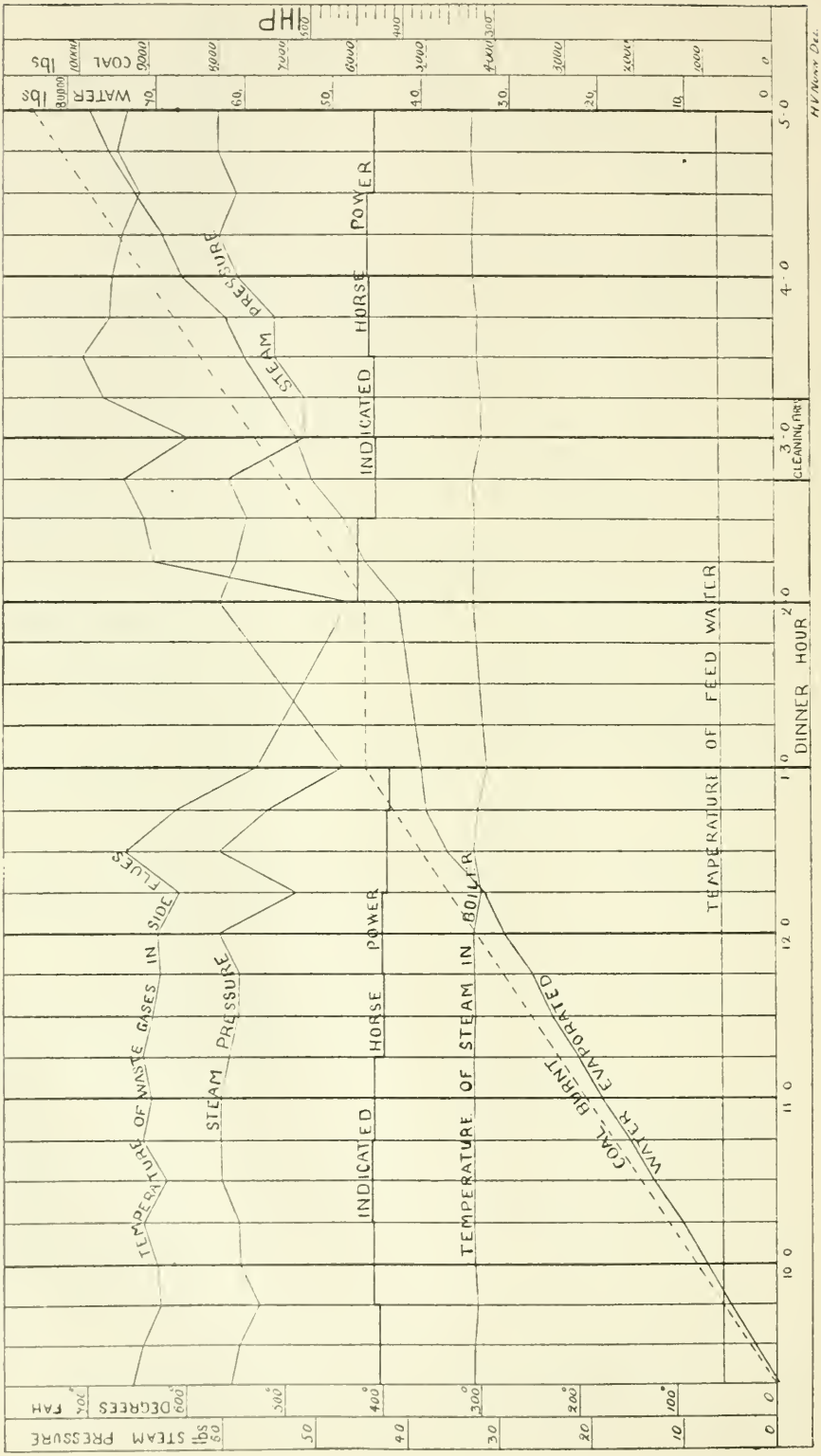
	Dry Coal.	Coal as Used.
Moisture	.....	3·91
Carbon	77·60	74·57
Hydrogen	5·32	5·11
Oxygen	6·83	6·56
Nitrogen	1·57	1·51
Sulphur (which burns away)	2·14	2·06
Mineral Matter (ash)	6·54	6·28
Total	100·00	100·00

Calorific value of dry coal ... ... 14·32 evaporative units.
,, coal as used ... 13·91 ,, ,,

TABLE XII

		No. 1.	No. 2.	Mean.
Conditions of Trials.				
Number of trials				
Dates of trials		18/5/98	18/5/98	....
Duration of trial		6h. 46m.	6h. 48m.	6h. 47m.
Steam pressure above atmosphere	lb	57·4	58·3	57·8
Mean temperature of steam	Deg. Fah.	304·8	305·7	305·2
Mean feed temperature	Deg. Fah.	55·0	54·0	54·5
Mean condenser discharge temperature.	Deg. Fah.	83·3	85·4	84·3
Mean air temperature (outside)	Deg. Fah.	57·0	56·0	57·5
Mean temperature of waste gases at end of 6 side flues	Deg. Fah.	639	631	635
Chimney draught at side flues	Inches	0·53	0·55	0·54
Coal Consumption.				
Coal burnt during trials, including one hour meal time	lb	10,665	11,058	10,861
Coal burnt per hour, steaming	lb	1,585	1,643	1,614
Coal burnt per square foot of grate per hour	lb	18·1	18·8	18·4
Coal burnt per square foot of heating surface per hour	lb	0·548	0·569	0·558
Feed Water.				
Feed water supplied during trials	lb	77,786	80,375	....
Feed per hour while steaming / Mean value from diagram 15 and 16	lb	11,650	12,080	11,365
Feed per hour per square foot of heating surface	lb	4·03	4·18	4·10
Engine Trials.				
Average steam pressure in boilers	lb	57·4	58·3	57·8
Average vacuum	lb	13·5	13·5	13·5
Barometer	Inches	29·9	29·7	29·8
Number of revolutions per minute		24·5	24·5	24·5
Indicated Horse Power:				
Two high-pressure cylinders	I.H.P.	253·9	271·6	262·7
Two low-pressure cylinders	I.H.P.	178·3	173·2	175·8
Total	I.H.P.	432·2	444·8	438·5
Common Results.				
Water evaporated per lb of coal as used	lb	7·35	7·36	7·35
Equivalent evaporation from and at 212 Deg. Fah.	lb	8·76	8·79	8·77
Efficiency of boilers	Per cent.	63·7	63·9	63·8
Feed water per I.H.P. per hour	lb	27·7	27·1	27·4
Coal per I.H.P. per hour		3·67	3·70	3·68

DIAGRAM 15.


WEDNESDAY MAY 18th 1898
STEAM PRESSURE lbs
DEGREES FAH
TEMPERATURE OF WASTE GASES IN FLUES
STEAM PRESSURE
INDICATED HORSE POWER
TEMPERATURE OF STEAM IN BOILER
COAL BURNT
WATER EVAPORATED
TEMPERATURE OF FEED WATER
INDICATED HORSE POWER
STEAM PRESSURE
DINNER HOUR
CLEANING FIRES
WATER lbs
COAL lbs
IHP

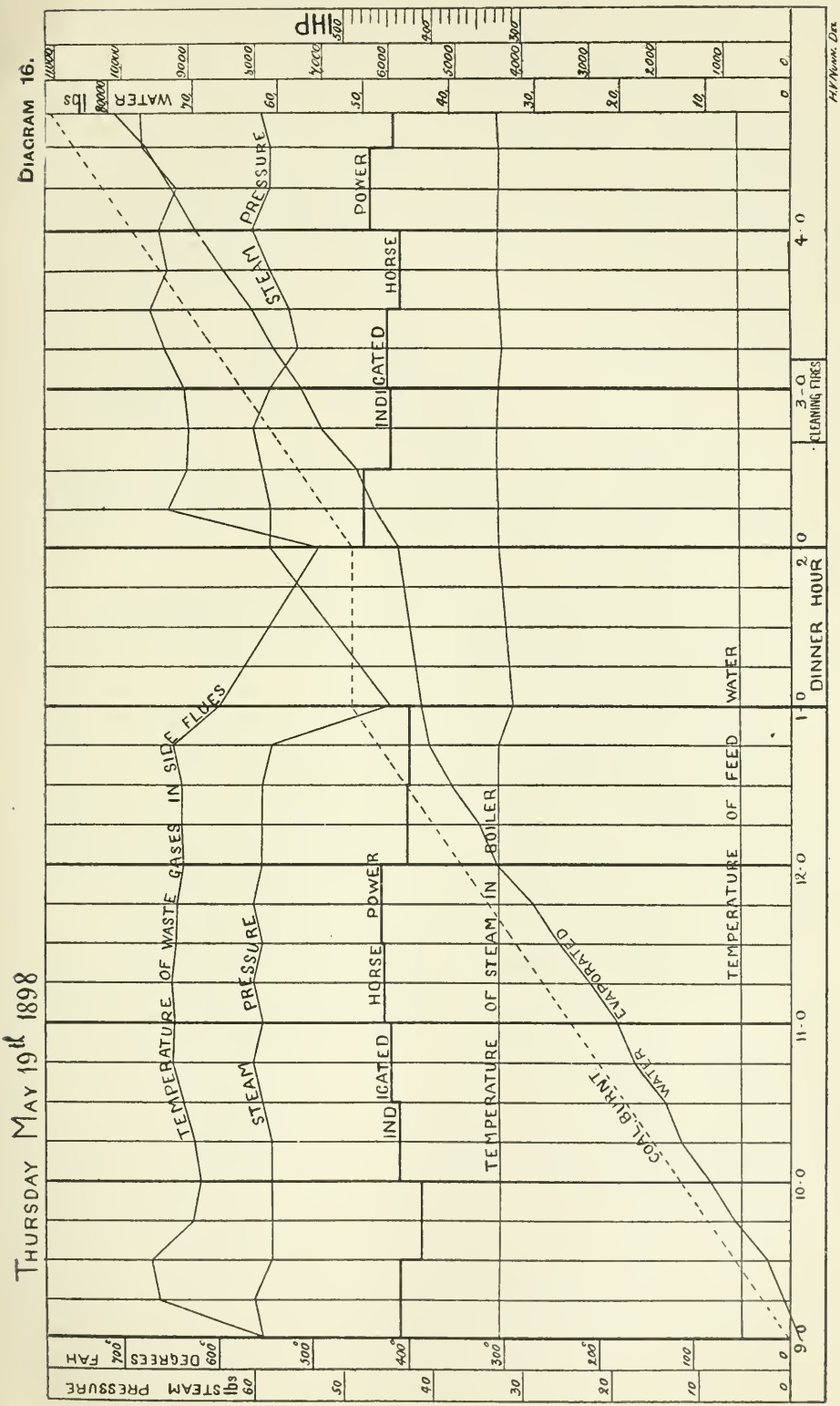


DIAGRAM 16.
THURSDAY MAY 19th 1898
H.V. Nunn Del.
STEAM PRESSURE lbs
DEGREES FAH
WATER lbs
IHP
TEMPERATURE OF WASTE GASES IN SIDE FLUES
STEAM PRESSURE
INDICATED HORSE POWER
TEMPERATURE OF STEAM IN BOILER
TEMPERATURE OF FEED WATER
COAL BURNT
WATER EVAPORATED
DINNER HOUR
CLEANING FIRES
9-0
10-0
11-0
12-0
1-0
2-0
3-0
4-0

ENGINE AND BOILER TRIALS AND DISCHARGED HEAT MEASUREMENTS AT ASTLEY MILL.

The following trials were carried out at the Astley Mill Co.'s Works, Dukinfield, on their boilers and engines. It was of importance that the true economic value of the engine should be obtained on account of alterations; it was therefore decided to measure not only the coal and feed water but also the condenser water. Salt injections, as described in the Transactions Inst. Naval Architects, vol. XXXVII., p. 226, were adopted for this latter purpose, because the volume of water to be measured was very large. The waste gases were collected continuously throughout the trials, but they appear to have become diluted, due to air leakage. The weight of the products of combustion has therefore been estimated from the changes of temperature which occur in the economiser, thus :—

$$\text{Weight of Waste Gases} = \frac{\text{Weight of Feed} \times \text{Increase of temperature.}}{\text{Decrease of temperature} \times \text{Specific heat.}}$$

The Specific heat of the waste gases is 0·236.

The weight of Steam as recorded in the indicator cards was measured, and compared with the steam supply. The difference of the two quantities, less loss by leakage, is moisture in Steam.

Engines.

Type : Horizontal Two-cylinder Compound, Jet condensing.
High-pressure Cylinder, 27in. diameter, 7ft. 0in. stroke.
Low-pressure Cylinder, 53in. diameter, 7ft. 0in. stroke.

Boilers.

Four Lancashire Boilers, 7ft. 6in. diameter, 30ft. 0in. long.
Grate Surface, 8 furnaces, 3ft. × 6ft., 144 sq. ft.
Heating Surface, 3,816 sq. ft. Hand Firing.

Fuel.

The coal was supplied from the 6ft. main of the Astley Colliery, Dewsny Pit, Dukinfield. Average Moisture in Coal, 3·63 per cent.

TABLE XIII.

Chemical Analysis by Messrs. Crace, Calvert, & Thomson.

	Dry Coal.	Coal as Used.
Moisture	.....	3·63
Carbon	77·50	74·68
Hydrogen	6·84	6·59
Oxygen	7·24	6·98
Nitrogen	1·68	1·62
Sulphur (all burnt)	2·03	1·96
Minerals (ash)	4·71	4·54
Total	100·00	100·00

Calorific value of Dry Coal ... ... 14·40 evaporative units.
,, ,, Coal as used ... ... 13·36 ,, ,,

TABLE XIV.

Conditions of Trial.				
No. of trials		No. 1.	No. 2.	Mean.
Dates of trials		21/4/98	22/4/98	....
Duration of trials		5h. 45m.	6h. 45m.	6h. 15m.
Steam pressure above atmosphere	lb	118·5	120·7	119·6
Mean temperature of steam	Deg. Fah.	349·0	350·2	349·6
Mean feed temperature, town mains	Deg. Fah.	47·5	47·5	47·5
Feed temperature after passing economiser	Deg. Fah.	224·5	224·0	224·2
Rise of feed temperature in economiser.	Deg. Fah.	177·0	176·5	176·7
Mean air temperature, outside	Deg. Fah.	53	51·5	52·2
Mean air temperature, engine-room	Deg. Fah.	82	80	81
Mean Temperature of Waste Gases:				
Before entering economiser	Deg. Fah.	711·1	711·4	711·2
After leaving economiser	Deg. Fah.	435·4	440·9	438·1
Decrease of temperature	Deg. Fah.	275·7	270·5	283·1
Waste gases per lb of feed water (*see below*)	lb	2·72	2·77	2·74
Draught at chimney	Inches	¾	¾	¾
Draught at end of boiler flues	Inches	½	½	½
Coal Consumption.				
Coal burnt during trials, including one hour meal time	lb	19,754	23,002	21,378
Clinker ashes and roof stones	lb	1,938	2,123	2,033
Difference	lb	17,816	20,874	19,345
Mineral matter in ashes	Per cent.	8·46	8·03	8·23
Averages from Diagrams 17 and 18:				
Coal burnt per hour's steaming	lb	3,475	3,516	3,495
Coal burnt per square foot of grate	lb	24·2	24·4	24·3
Coal burnt per square foot of heating surface	lb	0·91	0·92	0·92
Feed Water.				
Feed water supplied during trials	Gallons	14,200	17,000	15,600
Averages from Diagrams 17 and 18:				
Feed supply per hour	lb	25,719	25,943	25,831
Feed per square foot of grate	lb	178·6	180·2	179·4
Feed per square foot of heating surface	lb	6·74	6·80	6·77
Waste Gases.				
Waste gases per lb of coal (*see above*)	lb	20·9	19·9	20·4
Air supply per lb of coal	lb	19·9	18·9	19·4
Engine Trial.				
Average steam pressure in boilers	lb	118·5	120·7	119·6
Average barometer pressure	Inches	30	29·9	29·95
Average back pressure in condenser	lb	3·64	3·86	3·75
Number of revolutions per minute		53·3	53·8	53·5
Indicated Horse Power:				
High-pressure cylinder	I.H.P.	694·6	707·5	701·0
Low-pressure cylinder	I.H.P.	646·8	669·1	668·0
Total	I.H.P.	1,341·4	1,376·6	1,359·0

TABLE XIV.—(*continued*).

Engine Trial.—(*continued*).		No. 1.	No. 2.	Mean.
Average Steam Weight by Indicator Cards:				
High-pressure cylinder, per hour	lb	19,348	19,628	19,488
Low-pressure cylinder, per hour	lb	16,788	17,542	17,165
Common Results.				
Water evaporated per lb of coal, as used	lb	7·40	7·38	7·39
Equivalent evaporation from and at 212 Deg. Fah.	lb	9·00	8·97	8·98
Efficiency of boilers alone	Per cent.	57·00	56·8	56·9
Efficiency of economiser	Per cent.	10·1	10·1	10·1
Efficiency of boiler and economiser	Per cent.	67·1	66·9	67·0
Feed water per I.H.P. per hour	lb	19·17	18·85	19·01
Coal per I.H.P. per hour	lb	2·59	2·55	2·57
BALANCE SHEETS.				
Boilers.—*Evaporative Units per hour.*				
Heat used for warming feed in economiser	E.U.	4,720	4,750	4,735
Heat used for generating steam	E.U.	26,520	26,760	26,640
Heat used for evaporating moisture in coal	E.U.	2,760	2,760	2,760
Heat carried away by waste gases	E.U.	6,790	6,650	6,720
Heat remaining in unburnt ashes	E.U.	670	610	640
Heat radiated and unaccounted for	E.U.	7,190	7,670	7,430
Heat due to burning of coal = Totals	E.U.	48,650	49,200	48,920
Engine Balance Sheet. Evaporative units per hour in excess of 0° Fah.				
Heat contained in feed water from mains	E.U.	1,270	1,280	1,275
Heat supplied by boiler	E.U.	31,240	31,510	31,375
Heat supplied contained in injection water	E.U.	59,450	57,700	58,575
Total heat supplied to engines	E.U.	91,960	90,490	91,225
Heat discharged with ejection water	E.U.	85,600	84,700	85,150
Heat equivalent of I.H.P.	E.U.	3,550	3,640	3,595
Heat radiated, steam leakages, &c. (by difference)	E.U.	2,810	2,150	2,480
Total heat leaving engines	E.U.	91,960	90,490	91,225
Note.—*The weight of injection water mentioned above was found as follows:*				
Average weight of salt per gallon of brine	grains	8,080 to 13,780	7,750 to 8,550	....
Average weight of salt per gallon of injection water	grains	2·39	2·82	2·61
Average weight of salt per gallon of ejection water	grains	5·28	5·32	5·30
Increased saltness due to added brine	grains	2·89	2·50	2·69
Volume of brine added per hour	gallons	14·67 to 22·20	20·68 to 22·91	....
Volume of injection water estimated from above values, per hour	gallons	65,200	62,500	63,850
Ejection water volume, per hour	gallons	67,772	65,099	66,433

TABLE XIV.—(*continued*).

GENERAL BALANCE SHEET.	No. 1.	No. 2.	Mean.
Heat carried away with waste gases.... Per cent.	14·0	13·5	13·74
Other boiler losses..... Per cent.	21·8	22·4	22·12
Total boiler losses.....	35·8	35·9	35·86
Heat carried away with ejection water.. Per cent.	51·1	52·3	51·72
Heat lost by steam leakages, &c. ..... Per cent.	5·8	4·4	5·07
Total steam pipe and engine losses	56·9	56·7	56·79
Useful. Heat equivalent of I.H.P. .... Per cent.	7·3	7·4	7·35
Heat due to burning of coal=Total	100·0	100·0	100·00

DIAGRAM 17.

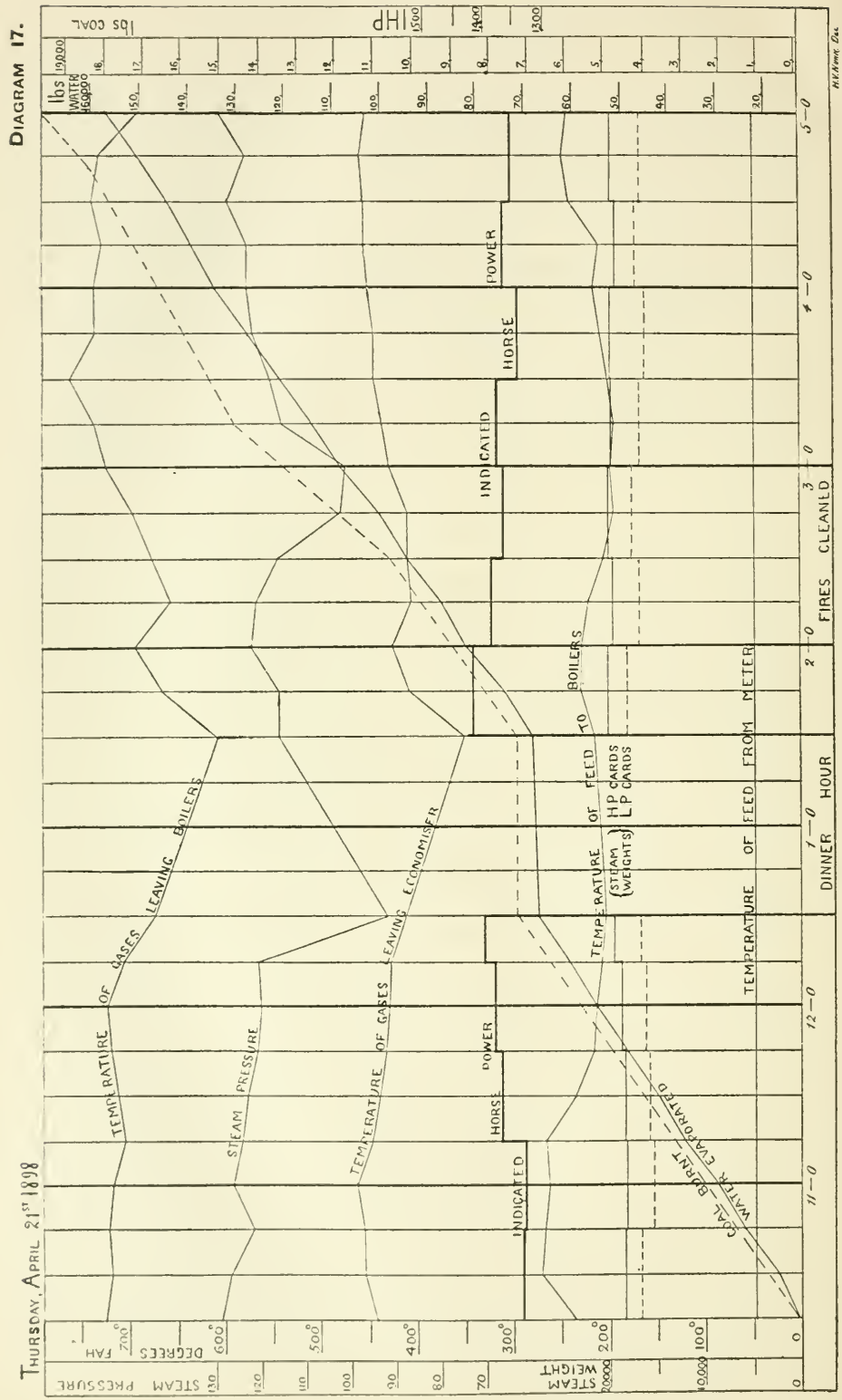
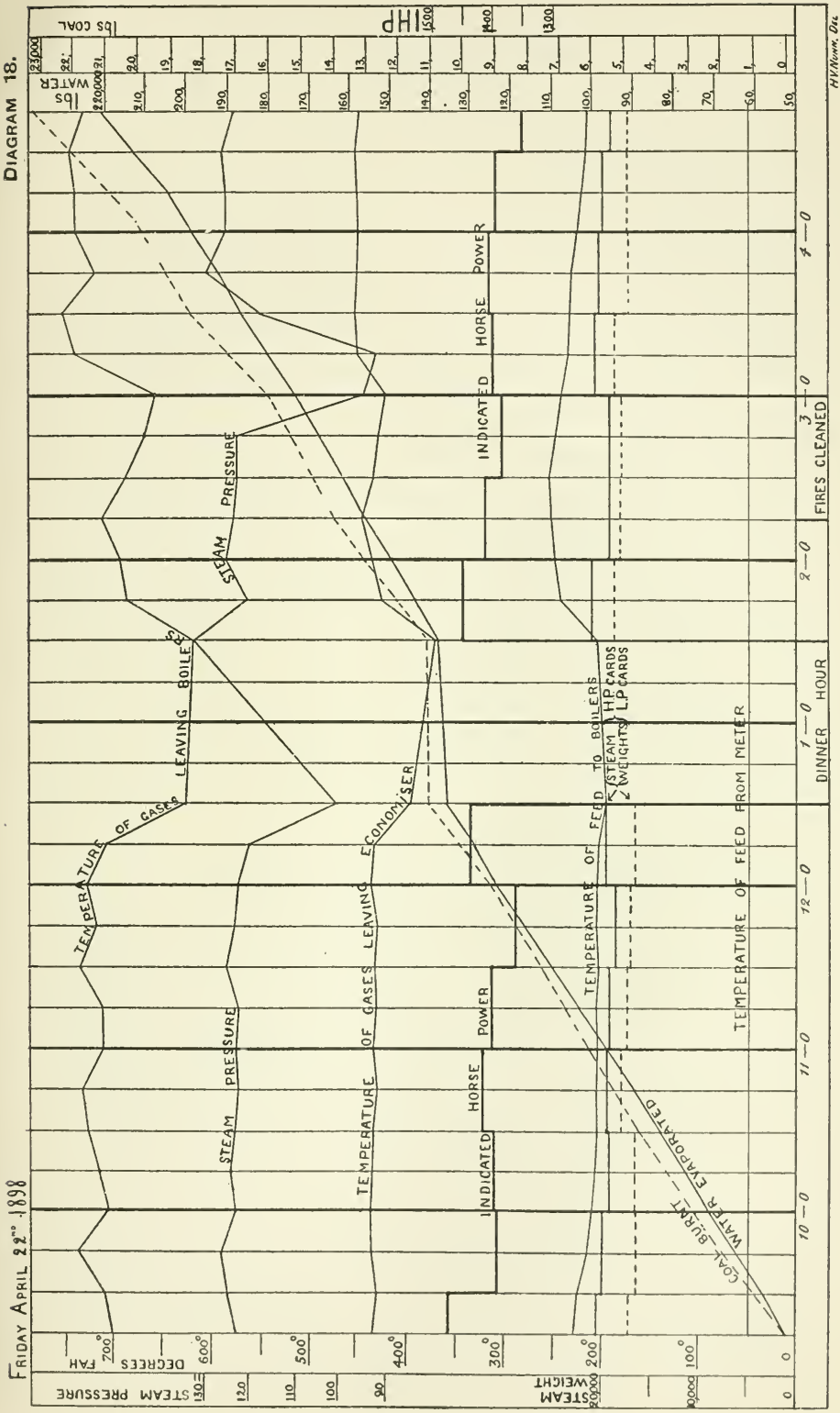

THURSDAY, APRIL 21ST 1898
STEAM PRESSURE
DEGREES FAH
STEAM WEIGHT
TEMPERATURE OF GASES LEAVING BOILERS
STEAM PRESSURE
TEMPERATURE OF GASES LEAVING ECONOMISER
HORSE POWER INDICATED
TEMPERATURE (STEAM WEIGHTS) OF FEED TO BOILERS
HP CARDS
LP CARDS
COAL BURNT
WATER EVAPORATED
HORSE POWER INDICATED
TEMPERATURE OF FEED FROM METER
DINNER HOUR
FIRES CLEANED
lbs WATER PER lb COAL
IHP
lbs COAL

DIAGRAM 18.


FRIDAY APRIL 22nd 1898
STEAM PRESSURE
DEGREES FAH
STEAM WEIGHT
TEMPERATURE OF GASES LEAVING BOILERS
STEAM PRESSURE
INDICATED HORSE POWER
TEMPERATURE OF GASES LEAVING ECONOMISER
TEMPERATURE OF FEED TO BOILERS
STEAM } H.P CARDS
WEIGHTS } L.P CARDS
COAL BURNT
WATER EVAPORATED
TEMPERATURE OF FEED FROM METER
INDICATED HORSE POWER
DINNER HOUR
FIRES CLEANED
lbs WATER
lbs COAL
IHP
H.V.Nunn, Del.

MESSRS. BROTHERS' PATENT FURNACE CO., RAWTENSTALL.

Trial of one Lancashire boiler and economiser fitted with Brothers' patent fire-brick furnace.

The boiler and economiser were comparatively new, stationed in a disused mill at Rawtenstall.

The dimensions of the boiler are: Diameter, 8ft.; length, 30ft.; grate surface, 2ft. × 6ft. × 3ft. = 36 sq. ft. The economiser consisted of 144 pipes. The furnaces were built of brick, and placed in front of the boiler. Firing was done by hand. Certain airholes in the furnaces were fitted with flaps, which opened with the fire-doors, and closed automatically some time after coaling. On account of the furnace heat, water was supplied to the ash trays. The ash trays were said to have been leaky, and all the water supplied may possibly not have been evaporated.

The steam generated by the boiler was allowed to escape through the safety-valve. The steam pressure was therefore constant throughout the trials.

The results of the trials are contained in the following Tables and in diagrams 19 and 20:—

TABLE XV.

Coal Analysis.			
Quality: Pemberton 4ft. slack.			
First Analysis: Moisture .....Per cent.	..	..	7·03
Fixed carbon.....Per cent.	..	..	49·89
Hydrocarbons, &c. .....Per cent.	..	..	32·15
Sulphur burnt .....Per cent.	..	..	1·56
Volatile constituents ....Per cent.	..	..	90·63
Sulphur in ash.....Per cent.	..	..	·29
Ash (mineral matter)....Per cent.	..	..	9·09
	..	..	100·00
Second Analysis: Moisture .....Per cent.	..	..	7·03
Carbon .....Per cent.	..	..	67·36
Hydrogen .....Per cent.	..	..	4·57
Oxygen .....Per cent.	..	..	8·60
Nitrogen.....Per cent.	..	..	1·79
Sulphur .....Per cent.	..	..	1·56
Ash (mineral matter) ..Per cent.	..	..	9·09
	..	..	100·00
Calorific value of coal as used .....E.U.	12·31	12·58	12·44

TABLE XVI.

No. of Trial.	No. 1.	No. 2.	Mean.
Date	19/1/97	20/1/97	..
Duration of trials ....hrs.	6·83	7·00	..
Steam pressure above atmosphere ....lb	60	60	60
Temperature feed water ....Deg. Fah.	45	47	46
Temperature leaving economiser ....Deg. Fah.	233	234	233·5
Rise of temperature in economiser....Deg. Fah.	188	187	187·5
Temperature of Flue Gases:			
Entering economiser ....Deg. Fah.	549	539	544
Leaving economiser....Deg. Fah.	319	293	306
Fall of temperature in economiser ..Deg. Fah.	230	246	238
Weight of waste gases per lb of feed water, estimate from above (*see below*)....lb	3·31	3·24	3·27
Draught at economiser end ....Inches	..	$\frac{7}{8}$	..
Coal Consumption.			
Coal burnt during trials ....lb	4,382	4,480	4,431
Ashes and clinker ....lb	345	357	351
Ashes and clinker ....Per cent.	7·9	8·0	7·95
Coal burnt per hour, estimated from Diagrams Nos. 19 and 20 ....lb	642	640	641
Coal burnt per sq. ft. of grate ....lb	17·8	17.8	17·8
Coal burnt per sq. ft. of heating surface....lb	·245	·245	·245
Smoke	None	None	None
Feed Water.			
Feed water during trial....Gallons	3,125	3,158	3,142
Feed water per hour, estimated from Diagrams Nos. 19 and 20 ....lb	4,575	4,512	4,543
Feed water per sq. ft. of grate ....lb	127	125	126
Feed water per sq. ft. of heating surface....lb	1·75	1·72	1·73
Feed water per lb of coal as used ....lb	7·13	7·05	7·09
Estimated air used per lb of coal (*see above*) ....lb	22·6	21·8	22·2
Equivalent value of feed water evaporated at and from 212 deg. Fah. per lb of coal as used ....lb	8·58	8·48	8·53
Equivalent value of feed water evaporated at and from 212 deg. Fah. per lb of coal as used, for boiler without economiser....lb	7·20	7·12	7·16
Efficiency.			
Boiler alone ....Per cent.	58·3	56·6	57·5
Economiser alone....Per cent.	11·2	10·7	10·9
Boiler and economiser....Per cent.	69·5	67·3	68·4

TABLE XVI.—(*continued*).

BALANCE SHEET. *Heat used, expressed in—*	Evaporative Units.	Per Cent.
Heating and evaporating water	8·53	78·6
Heat carried away by waste gases	1·36	10·9
Evaporating moisture in coal and water in ash trays	·53	4·3
Heat lost by radiation and unaccounted for (by difference)	2·02	16·2
Total heat in coal as used	12·44	100·0

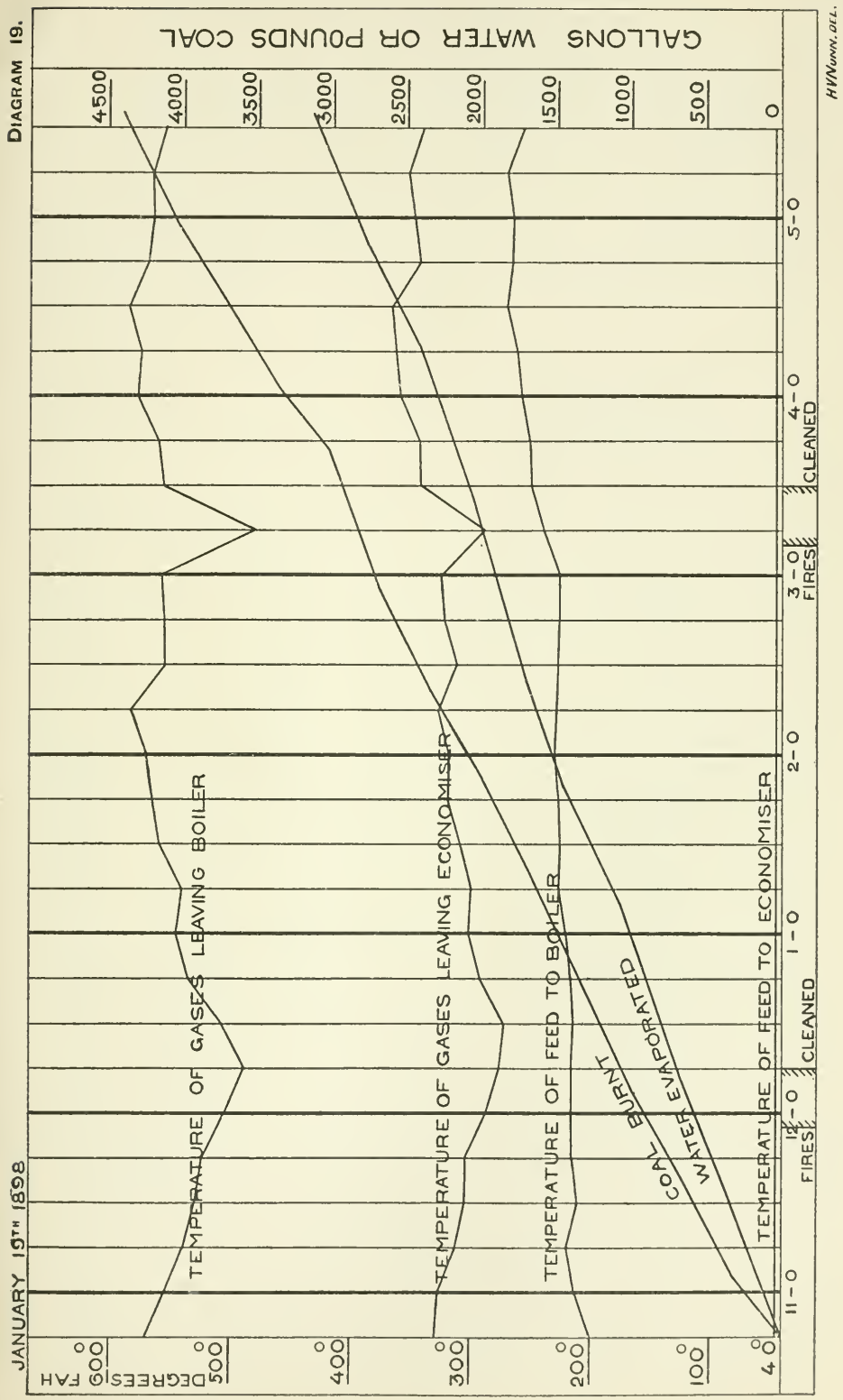


DIAGRAM 19.
JANUARY 13TH 1898
DEGREES FAH
600°
500°
400°
300°
200°
100°
40°
GALLONS WATER OR POUNDS COAL
4500
4000
3500
3000
2500
2000
1500
1000
500
0
TEMPERATURE OF GASES LEAVING BOILER
TEMPERATURE OF GASES LEAVING ECONOMISER
TEMPERATURE OF FEED TO BOILER
COAL BURNT
WATER EVAPORATED
TEMPERATURE OF FEED TO ECONOMISER
11-0
12-0
1-0
2-0
3-0
4-0
5-0
FIRES
CLEANED
FIRES
CLEANED
H.W.WOOD, DEL.

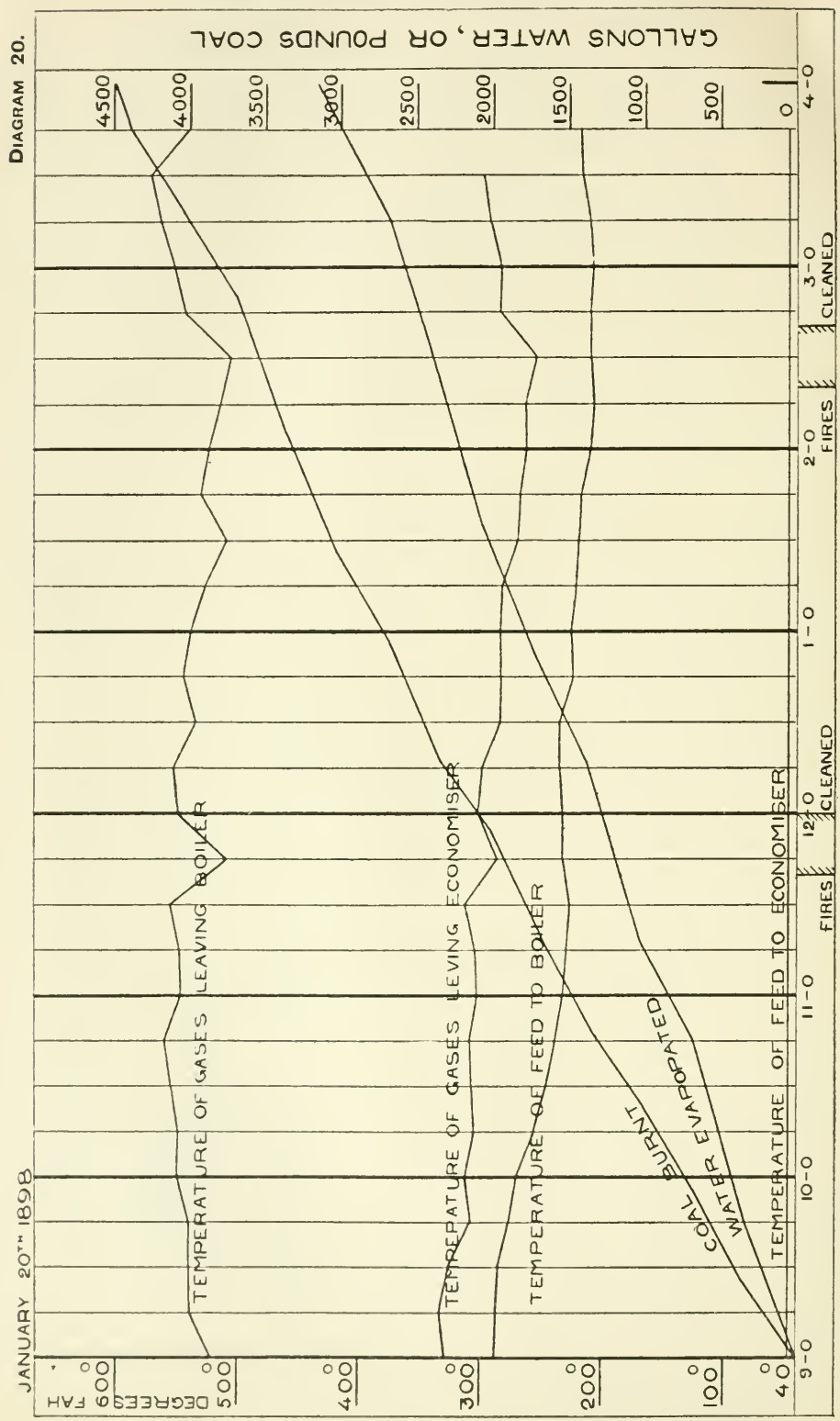


DIAGRAM 20.
JANUARY 20TH 1898
DEGREES FAH.
600°
500°
400°
300°
200°
100°
40°
GALLONS WATER, OR POUNDS COAL
4500
4000
3500
3000
2500
2000
1500
1000
500
0
TEMPERATURE OF GASES LEAVING BOILER
TEMPERATURE OF GASES LEVING ECONOMISER
TEMPERATURE OF FEED TO BOILER
COAL BURNT
WATER EVAPORATED
TEMPERATURE OF FEED TO ECONOMISER
9-0
10-0
11-0
FIRES
12-0
CLEANED
1-0
2-0
FIRES
3-0
CLEANED
4-0
H.W.HUNT DEL.

CONCLUSION.

The above economic trials are reproduced here by permission of the respective firms, and add still further to our stock of knowledge of engine and boiler performances. The details of practical experiences of strengths of various parts of boilers will it is hoped be of service to those of our members who may be asked to design lighter structures than are customary; but these collected facts do not warrant a departure from the present more general practice, where absolute safety from boiler explosions is one of the first considerations.

I am, Gentlemen,

Yours faithfully,

C. E. STROMEYER,
Chief Engineer.

Manchester Steam Users' Association,
9, Mount Street,
Manchester.

MANCHESTER STEAM USERS' ASSOCIATION

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DISTINCTIVE FEATURES OF THE MANCHESTER STEAM USERS' ASSOCIATION.

This Association was founded in the year 1854, by Sir William Fairbairn, C.E.; Sir Thomas Bazley, M.P.; Sir Joseph Whitworth, Bart., C.E.; Henry Houldsworth, Esq., and other philanthropic gentlemen, for the purpose of preventing steam boiler explosions by competent scientific inspection of the boilers, and thus of saving human life.

This Association was the first institution to establish periodical boiler inspection on a practical basis.

The Association is not a Joint Stock Company. There are no shareholders to whom dividends are paid out of the members' subscriptions, but the income is appropriated solely to promote the direct objects of the Association. The Committee of Management is elected annually at a general meeting of the body of subscribers.

After a boiler has been examined and found fit for its working pressure, the Association gives a pecuniary guarantee of its safety to the extent of £1,000 or £2,000. In the event of explosion the guarantee covers both loss of life and property, as well as claims under the Employers' Liability Act and the Workmen's Compensation Act. The Association does not guarantee boilers on the principle of averages, but as the result of competent scientific inspection. Its object is Prevention, not Compensation; and its fundamental principle is—*No Inspection, No Guarantee.*